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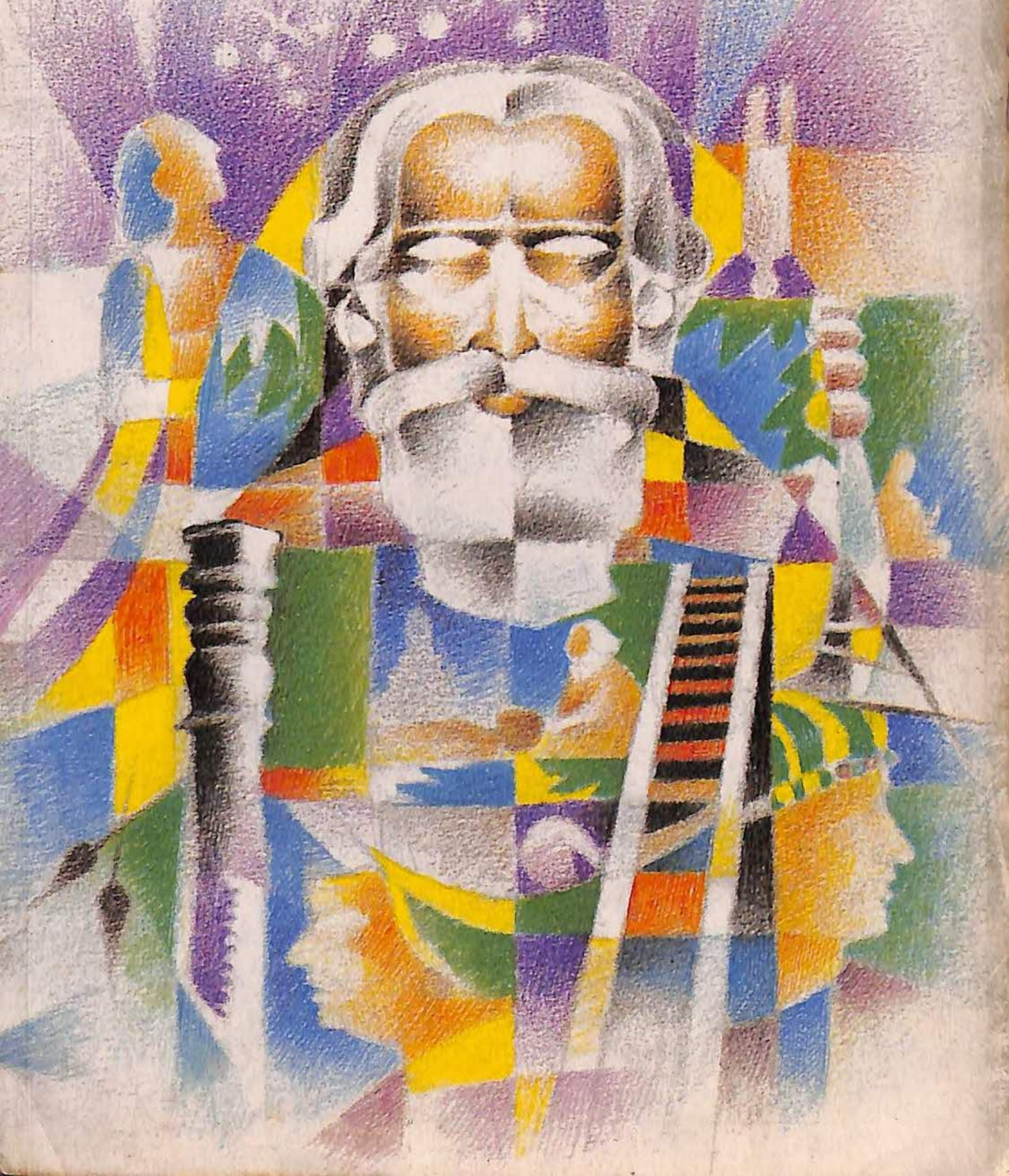
OUR SCIENTISTS



Our Scientists won the second prize in the non-fiction category in the Competition for Writers of Children's Books held in 1983 by the Children's Book Trust.

The author, Dilip M. Salwi, is Asst. Editor of *Science Reporter,* a magazine published by the Council of Scientific and Industrial Research.

Printed 1986
Reprinted 1987

ISBN 81 - 7011 - 318 - 0

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Published by Children's Book Trust, Nehru House, 4 Bahadur Shah Zafar Marg, New Delhi, and printed at the Trust's press, the Indraprastha Press, New Delhi.

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OUR SCIENTISTS

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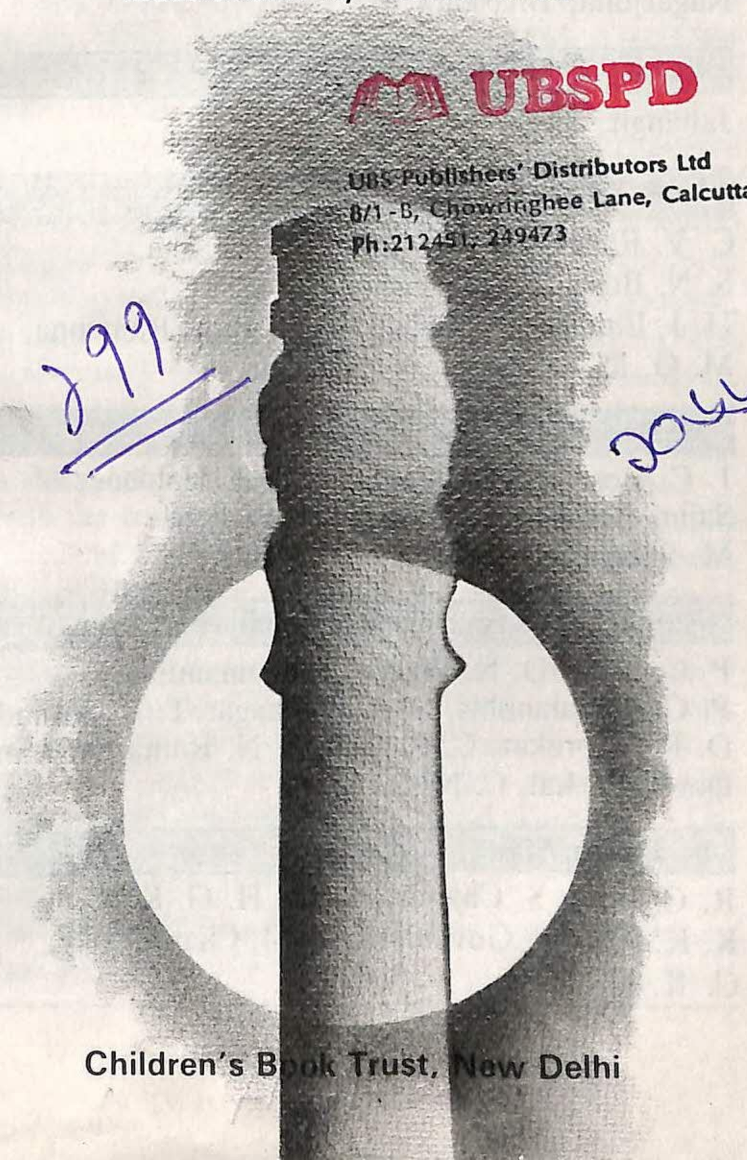

UBSPD
UBS Publishers' Distributors Ltd
8/1-B, Chowringhee Lane, Calcutta-700 016
Ph:212451, 249473

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2044

Children's Book Trust, New Delhi

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Foreword

Most Indians are aware that they have a great heritage, but few would include science in it. This is mainly because during centuries of alien rule they have been led to believe that science is an import from Europe. They tend to forget the many significant contributions to science India had made for hundreds of years before the first Europeans came to India.

There is evidence that more than 3,000 years before the birth of Christ, people of this sub-continent had much scientific knowledge. Relics of the Indus Valley civilization found at Harappa and Mohenjo-daro (now in Pakistan) indicate that their cities were well-planned, with excellent water supply and drainage systems. The progress they had made in agriculture,brick-making, craft and industry was remarkable. Their clothes were made of cotton. For reasons yet unknown, this civilization decayed and was lost. The cities got buried.

With the coming of the Aryans to India around 2000 B.C., about 1,000 years after the collapse of the Indus Valley civilization, a new page began in the history of science in the land. There is evidence to indicate that the Aryans had a scientific attitude. A natural law was believed to govern the universe. This seemingly disordered and diverse world was explained in terms of the *panchabhutas* (five factors), namely, *prithvi*(earth), *ap* (water), *tejas* (heat), *vayu* (air) and *akasa* (sky). The human body was a combination of the *panchabhutas* and the soul.

The Aryans were a highly religious race. Every ritual or sacrifice was conducted at an auspicious hour determined by the planetary positions and in a precisely built temple. They were thus expert astronomers (or astrologers), mathematicians and geometricians. Their calendar was luni-solar, which was based on the movement of both the moon and the sun. They had identified various *nakshatras* (constellations) and had named the months after them.

In mathematics, they could count numbers even up to 10^{12}, while the Greeks could count only upto 10^4 and the Romans upto 10^8. The Pythagorus theorem can also be traced to the Aryans' *Sulbasutras*. Values of irrational numbers such as $\sqrt{2}$ and $\sqrt{3}$ were also known to them to a high degree of approximation. Knowledge of permutation and combination is also found in the Vedic texts.

The theory that change of seasons, minute organisms in the body and hereditary factors cause disease was widely accepted. A system of medicine, *Ayurveda*, in which surgery had a special place was practised. Methods of surgical treatment were advanced and later the Arabs and the Greeks adopted them. Indian herbs were also sought after in the Roman world.

Besides the human body, the internal structure of plants and animals was also studied, their various parts identified and named. In agriculture, the method of "fallow rotation" — keeping the land untilled for some time after a series of crops had been sown and harvested — to improve the fertility of the soil was practiced.

The golden age of science in India was from the fourth century B.C. to the sixth or seventh century A.D. With prosperity in the land, science flowered under the Maurya, Shaka, Kushana and Gupta empires. There were renowned universities at Nalanda, Varanasi and Taxila (now in Pakistan). There was much exchange of scholars with neighbouring and distant lands.

Outstanding contributions were made to mathematics, astronomy and medical science. The concept of zero was discovered around the fifth century A.D. Another discovery was differential calculus, but it was not further explored.

The astronomical treatises, the Siddhantas, were also written during this period. One of them, the *Suryasiddhanta,* is known the world over for its accurate data. Texts were written on morphology, physiology and the germination process of plants. A system of nomenclature was also developed, which gave the botanical significance, therapeutic value and habitat of plants.

With the Muslim invasion in the 12th century, India's ancient culture and learning remained intact only in some pockets of Maharashtra and Gujarat and in southern India. But Sanskrit texts were translated into Persian and Arabic and what knowledge India had acquired was passed onto the Arab world and then to Europe.

While wars and invasions plagued India, Europe was passing through the Renaissance period of science. Copernicus's heliocentric theory of the universe, Galileo's astronomical discoveries and Isaac Newton's laws of motion had gained acceptance. The search for truth — science — was catching up everywhere.

History was not on India's side. She could not participate in the Renaissance and become one of the earliest homes of modern science. After the Mughals came the Portuguese, the Dutch, the French and finally the British. These invasions wrought irreparable damage. Indians themselves forgot their glorious scientific past until the Indus Valley civilization was discovered in 1921.

A major benefit to Indian science during British rule was the spread of education in English, the language of modern science. The learning of science got a fillip in 1857 when three universities were created at Calcutta, Bombay and Madras. In 1876 a rich physician, Mahendra Lal Sircar, set up the first scientific research institution at Calcutta. Known as the Indian Association for the Cultivation of Science, it soon became the focus of scientific activities in pre-independence India.

With India becoming independent on August 15, 1947, a new page was opened in the history of science in the land. There was a remarkable expansion of facilities for scientists. Research began and prospered in many fields. Progress was rapid, at times spectacular. India is now a member of the nuclear club, the space club, the Antarctica exploration club. It has the world's third largest pool of trained technologists, next only to the USA and the Soviet Union, though it is still a developing nation. While much remains to be done for India to catch up with the advanced countries, much has been done.

Dr. Mahendra Lal Sircar

Trail-blazers

Susruta

IT was midnight when Susruta was awakened by a frantic knocking at the door.

"Who's out there?" asked the aged doctor, taking a lighted torch from its socket in the wall and approaching the door.

"I'm a traveller, my revered Susruta," was the anguished reply. "A tragedy has befallen me. I need your help....."

Susruta opened the door. What he saw was a man kneeling before him, tears flowing from his eyes and blood from his disfigured nose.

"Get up, my son, and come in," said Susruta. "Everything will be all right. But be quiet, now."

He led the stranger to a neat and clean room, with surgical instruments on its walls. Unfolding a mattress he asked him to sit on it after taking off his robe and washing his face with water and the juice of a medicinal plant. Susruta then offered the traveller a mug of wine and began preparing for the operation.

With a large leaf of creeper brought from the garden, he measured the size of the stranger's nose. Taking a knife and forceps from the wall, he held them over a flame and cut a strip of flesh from the stranger's cheek. The man moaned, but the wine had numbed his senses.

After bandaging the cut in the cheek, Susruta cautiously inserted two pipes into the stranger's nostrils and transplanted the flesh to the disfigured nose. Moulding the flesh into shape he dusted the nose with powdered liquorice, red sandalwood and extract of Indian barberry. He then enveloped the nose in cotton, sprinkled some refined oil of sesame on it and finally put a bandage. Before the traveller left, he was given instructions on what to do and what not to and a list of medicines and herbs he was to take regularly. He was also asked to come back after a few weeks to be examined.

In this manner did Susruta mend a nose some 26 centuries ago. And what he did is not greatly different from what a plastic surgeon would do today. In fact, Susruta is today recognised as the father of plastic surgery all over the world. His treatise, *Susrutasamhita,* has considerable medical knowledge of relevance even today. It indicates that India was far ahead of the rest of the world in medical knowledge. In the eighth century A.D. *Susrutasamhita* was translated into Arabic as *Kitab-Shaw Shoon-a-Hindi* and *Kitab-i-Susrud.*

Born in the sixth century B.C., Susruta was a descendant of the Vedic sage Visvamitra. He learnt surgery and medicine at the feet of Divodasa Dhanvantari in his hermitage at Varanasi. Later, he became an authority in not only surgery but other branches of medicine.

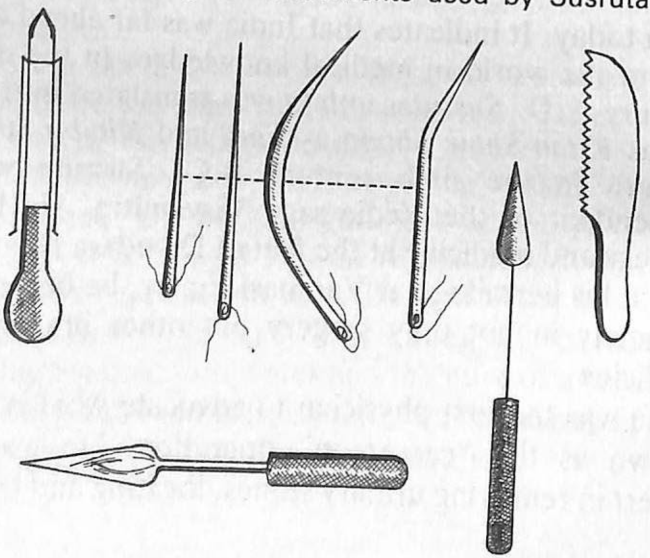
He was the first physician to advocate what is today known as the "caesarean" operation. He was also expert in removing urinary stones, locating and treating fractures and doing eye operations for cataract. Several centuries before Joseph Lister, he put forth the concept of asepsis. His suggestion to give wine to patients about to be operated upon makes him also the father of anaesthesia.

In his treatise, Susruta lists 101 types of instruments. His *Samdamsa yantras* are the first forms of the modern surgeon's spring forceps and dissection and dressing forceps. In fact, his system of naming surgical tools after the animals or birds they resemble in shape, for example crocodile forceps, hawkbill forceps, is adopted even today.

Susruta was also an excellent teacher. He told his pupils that one could become a good physician only if one knew both theory and practice. He advised his pupils to use carcases and models for practice before surgery.

In addition to classifying worms that infect the human body, leeches for bloodletting, medicinal herbs, alkalis and metals, Susruta gave a vague classification of animals.

Surgical instruments used by Susruta



Charaka

A physician who fails to enter the body of a patient with the lamp of knowledge and understanding can never treat diseases. He should first study all the factors, including environment, which influence a patient's disease, and then prescribe treatment. It is more important to prevent the occurrence of disease than to seek a cure.

These remarks appear rudimentary today, but they were made by Charaka, some 20 centuries ago in his famous Ayurvedic treatise *Charakasamhita*. The treatise contains many more such remarks which are held in reverence even today. Some of them are in the fields of physiology, etiology and embryology.

Charaka was the first physician to present the concept of digestion, metabolism and immunity. According to him a body functions because it contains three *dosha* or humours, namely, bile, phlegm and wind. These *dosha* are produced when *dhatus*, namely, blood, flesh and marrow, act upon the food eaten. For the same quantity of food eaten, one body, however, produces *dosha* in an amount different from another body. That is why one body is different from another. For instance, it is more weighty, stronger, more energetic.

Further, illness is caused when the balance among the three *dosha* in a human body is disturbed. To restore the balance he prescribed medicinal drugs. Although he was aware of germs in the body, he did not give them any importance.

Charaka also knew the fundamentals of genetics. For instance, he knew the factors determining the sex of a child. A genetic defect in a child, like lameness or blindness, he said, was not due to any defect in the mother or the father, but in the ovum or sperm of the parents — an accepted fact today.

Charaka also studied the anatomy of the human body and various organs. He gave 360 as the total number of bones, including teeth, present in the body. He wrongly believed that the heart had one cavity, but he was right when he considered it to be a controlling centre. He claimed that the heart was connected to the entire body through 13 main channels. Apart from these channels, there were countless other ones, some big and some small, which supplied not only nutrients to various tissues but also provided passage to waste products. He also claimed that any obstruction in the main channels led to a disease or deformity in the body.

Under the guidance of the ancient physician Atreya, Agnivesa had written an encyclopedic treatise in the eighth century B.C. However, it was only when Charaka revised this treatise that it gained popularity and came to be known as *Charakasamhita*. For two millenniums it remained a standard work on the subject and was translated into many foreign languages, including Arabic and Latin. However, there is nothing known about Charaka as a person. It is said that he was the son of a sage who travelled from place to place on foot to cure the suffering masses.

Kanada

What is the relationship between man, the universe and their creator? This question has always intrigued philosophers and thinkers. Between 600 B.C. and 200 A.D. there were several attempts by Indian philosophers to find an answer to the question.

One of these was Kanada, who, in about 600 B.C. at Prabhasa propounded the *Vaisesikasutra* (Peculiarity Aphorisms). Today, we realise that these *sutras* are a blend of science, philosophy and religion. Their essence is the atomic theory of matter. If Kanada's *sutras* are analysed, one would find that his atomic theory was far more advanced than those forwarded later by the Greek philosophers, Leucippus and Democritus. In fact, he gave the name *paramanu* (atom) to an indivisible entity of matter.

According to Kanada, everything is made up of *paramanu*. When matter is divided, then further divided, till no further division is possible, the remaining indivisible entity is called *paramanu*. This entity does not exist in a free state, nor can it be sensed through any human organ. It is eternal and indestructible.

Kanada added — and it is here that he took a lead over other philosophers — that there are a variety of *paramanu* as different as the different classes of substances then believed to exist, namely, earth, water, air and fire. Each *paramanu* has a peculiar property which is the same as the class of substance it belongs to. It is only because of this peculiarity of *paramanu* that the theory was called *Vaisesikasutras.*

Kanada also claimed that an inherent urge made one *paramanu* combine with another. If two *paramanu* belonging to one class of substance combined, a *dwinuka* (binary molecule) was produced, which had properties similar to those of the two original *paramanu. Paramanu* belonging to different classes of substance could also combine in large numbers.

The idea of chemical change was also put forward by Kanada. He claimed that heat was responsible for any change. The properties of *paramanu* also changed when heated. He gave the examples of the blackening of a new earthen pot and the ripening of a mango to illustrate the action of heat. All things seen in the universe were, therefore, formed, Kanada said, because of the peculiarity of *paramanu,* their variety, the variety of ways in which they combined and the action of heat.

Patanjali

Although the *Upanishads* and the *Atharvaveda* mention *yoga,* it was only in the second century B.C. that its fundamentals and techniques were adequately presented. The man who did this was Patanjali in his *Yogasutras* (Yoga aphorisms).

According to Patanjali, there are channels called *nadi* and centres called *chakra* in the human body. If these are tapped, the hidden energy in the body called *Kundalini* can be released, enabling the body to acquire "supernatural" powers. Patanjali gives eight stages. *Yama* (universal moral commandments), *Niyama* (self-purification through discipline), *Asana* (posture), *Pranayama* (breath-control), *Pratyahara* (withdrawal of mind from external objects), *Dharana* (concentration), *Dhyana* (meditation), and *Samadhi* (state of superconsciousness). It is the last stage which is the more difficult and which enables one to attain "Godhead".

Patanjali gives a beautiful analogy to explain how God is attained through *yoga.* Our mind, he says, is like the surface of a pond. Just as we cannot see the jewel lying at the bottom of the pond because of the breeze disturbing its surface, we do not see the divine in us because our mind is in constant agitation. If the surface of the pond is undisturbed, one can see the jewel at the bottom. So also, if the mind is kept calm, with the doors to the external world closed, one can see God within.

Only in the last few decades have scientists begun to recognise the powers of *yoga.* It has now been established by experiments that through the practice of *yoga* several ailments, mental and physical, can be cured. Tests conducted on *yogis* show that they do acquire extraordinary powers. For instance, they can live without oxygen or food for a long time. Research is now in progress in laboratories all over the world to probe further the merits of *yoga.* What Patanjali advocated several centuries is now receiving the attention it deserves.

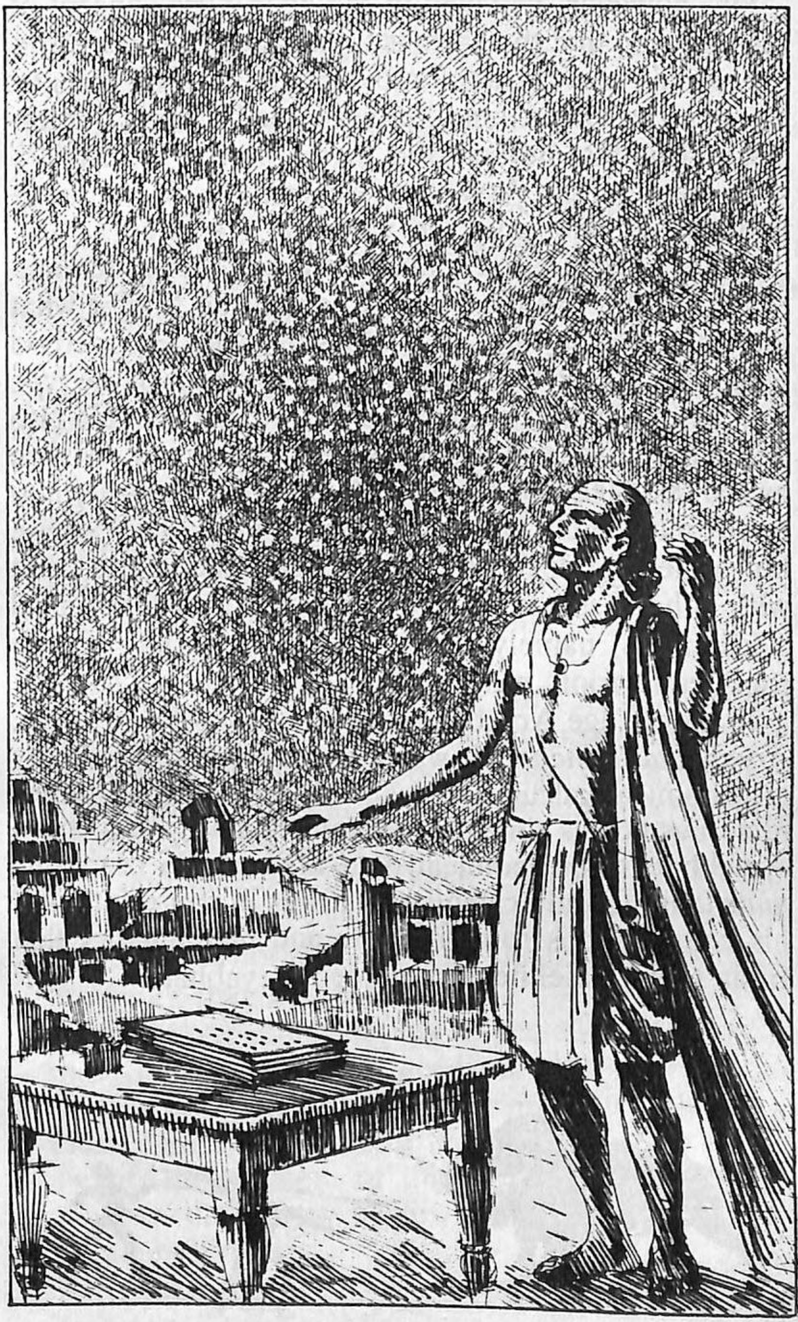
Aryabhata

Nearly five hundred years after the birth of Christ a ritual was held near Khagola, the famous astronomical observatory at the University of Nalanda near Kusumapura (Patna), to mark the "birth" of a treatise that was to lay the foundation of a new school of thought in astronomy.

When the bell at the university tolled at 12 noon on March 21, 499 A.D., a chorus of *vedic* chants filled the air. And priests, after prayers before a *havan,* led a 23-year-old astronomer to a platform. Silence prevailed as the astronomer sprinkled holy water on the parchment and pen lying on a desk placed on the platform. Chanting holy verses, he gazed at the sun overhead and prostrated himself in obeisance before sitting at the desk. Taking the pen, he wrote the first letter of the treatise while the priests chanted *slokas* and the large crowd of learned men showered flowers on him.

The young astronomer was Aryabhata and the treatise was *Aryabhatiya.* Born in 476 in Kerala, Aryabhata had come to complete his studies at the University of Nalanda, which was then a great centre of learning. When his treatise was recognised as a masterpiece, the then Gupta ruler Buddhagupta, made him head of the university.

Aryabhata was the first to deduce that the earth is round and that it rotates on its own axis, creating day and night. He declared that the moon is dark and shines only because of sunlight. Solar and lunar eclipses, he believed, occurred not because Rahu gobbled the sun and the moon, as Hindu mythology claimed, but because of the shadows cast by the earth and the moon.



He, however, believed in the geocentric concept of the universe that the earth is the centre of the universe. To explain the "erratic" movements of some planets, he, like the Greek king Ptolemy, made use of "epicycles". But his method was superior to Ptolemy's.

In mathematics Aryabhata's contributions are equally valuable. He gave the value of π (pi) as 3.1416, claiming, for the first time, that it was an approximation. And he was the first mathematician to give what later came to be called the tables of Sines. His method to find a solution to indeterminate equations of the type $ax - by = c$ is also recognised the world over. He also devised a novel method to express large numbers such as 100,000,000,000 in words. He developed this method to write unweidly numbers in poetic form. The concise but somewhat difficult-to-grasp *Aryabhatiya* also dealt with other aspects of mathematics and astronomical calculations, namely, geometry, mensuration, square root, cube root, progression and celestial sphere.

In his old age Aryabhata also wrote another treatise, *Aryabhatasiddhanta*. It was a text-book for day-to-day astronomical calculations as well as a guide to determine auspicious times for various rituals. Even today Aryabhata's astronomical data are used in preparing *panchangs* (Hindu calendars). It was in appreciation of his contributions to astronomy and mathematics that India's first satellite was named Aryabhata.

Varahamihira

"Can it be true?" King Vikramaditya asked in anguish, looking around the well-lit and crowded court.

No one replied. All were shocked by the royal astrologer's prediction.

"Yes, my lord, this is so, however bitter it may be for you," replied the royal astrologer, breaking the silence. His voice was full of grief. Yet it was authoritative. "The position of the planets predicts the death of the prince at the age of 18."

While the King controlled his emotions, the Queen, sitting beside him, could not contain herself. "No! No!" she wailed. "My lord, you should see to it that this prediction proves false."

Though the King had full faith in his astrologer, Mihira, he took every precaution to save his son. But, on the predicted day, a boar killed the prince. When the news reached the King, he immediately summoned Mihira to his court.

"I am defeated, you have won," he told Mihira.

The astrologer was as sad as the king. He said, "My Lord, I have not won. It is the science of astronomy and astrology that has won."

"Whatever it may be, my respected astrologer," said the King, "it has convinced me that your science is nothing but truth. And for your mastery of the subject, I now confer upon you the Magadha kingdom's greatest award, the emblem of the *varaha* (boar)."

From that time Mihira came to be known as Varahamihira.

Varahamihira was born in 499 A.D. into a family of Brahmins settled at Kapittha, a village near Ujjain. His father, Adityadasa, was a worshipper of the sun god and it was he who taught Mihira astrology. On a visit to Kusumapura (Patna) young Mihira met the great astronomer and mathematician, Aryabhata. The meeting inspired him so much that he decided to take up astrology and astronomy as a lifetime pursuit.

At that time, Ujjain was the centre of learning, where many schools of arts, science and culture were blooming in the prosperity of the Gupta reign. Mihira, therefore, shifted to this city, where scholars from distant lands were gathering. In due course, his astrological skills came to the notice of Vikramaditya Chandragupta II, who made him one of the Nine Gems of his court. Mihira travelled widely, even as far as Greece. He died in 587.

Varahamihira was learned in the *Vedas*, but was not a blind believer in the supernatural. He was a scientist. Like Aryabhata before him, he declared that the earth was spherical. In the history of science he was the first to claim that some "force" might be keeping bodies stuck to the round earth. The force is now called gravity.

He committed one blunder, however. He was sure that the earth was not in motion. "Had it been so," he said, "a bird moving in the direction opposite to the earth's motion (which is westwardly) would return to its nest as soon as it had flown from it."

Varahamihira made some significant observations in the fields of ecology, hydrology and geology. His claim that plants and termites serve as indicators of underground water is now receiving attention in the scientific world. He was also a prolific writer. His mastery of Sanskrit grammer and poetic metre enabled him to express himself in a unique style.

His encyclopedic knowledge and his lively presentation of subjects, as dry as astronomy, made him a celebrated figure. His treatises such as *Panchasiddhantika* (Five Principles), *Brihatsamhita* (Master Collection), *Brahjjataka* (Astrological work), have put him on as high a pedestal in astrology as Kautilya's in political philosophy, Manu's in law, Panini's in grammar.

About his own treatises Varahamihira says: "The science of astrology is a vast ocean and it is not easy for everyone to cross it. My treatises provide a safe boat." That was no boast. Even now they are acknowledged as masterpieces.

Brahmagupta

The mathematician who first framed the rules of operation for zero was Brahmagupta. He was also to give a solution to indeterminate equations of the type $ax^2+1=y^2$ and the founder of a branch of higher mathematics called "Numerical analysis". No wonder Bhaskara, the great mathematician, conferred on him the title of *Ganakachakrachudamani,* the gem of the circle of mathematicians.

Brahmagupta was born at Bhillamala (Bhinmal), in Gujarat, in 598 A.D. He became court astronomer to King Vyaghramukha of the Chapa dynasty. Of his two treatises, *Brahmasphutasiddhanta* and *Karanakhandakhadyaka,* the first is the more famous. It was a corrected version of the old astronomical text, *Brahmasiddhanta.* It was translated into Arabic, but erroneously titled *Sind Hind.* For several centuries the treatise

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remained a standard work of reference in India and the Arab countries.

Brahmasphutasiddhanta also contains chapters on arithmetic and algebra. Brahmagupta's major contribution is the rules of operation for zero. He declared that addition or subtraction of zero to or from any quantity, negative or positive, does not affect it. He also added that the product of any quantity with zero is zero and division of any quantity by zero is infinity. He, however, wrongly claimed that division of zero by zero was zero.

He also framed rules to solve a simple equation of the type $ax + b = 0$ and a quadratic equation of the type $ax^2 + bx + c = 0$, as well as methods to sum up a geometric series. Besides, he noted the difference between algebra and arithmetic and so was the first mathematician to treat them as two separate branches of mathematics.

Brahmagupta's *Karanakhandakhadyaka* is a handbook on astronomical calculations. In this he effectively used algebra for the first time in calculations. But Brahmagupta always was careful not to anger the priests. His views were orthodox, in keeping with the beliefs held during those times, and he criticized Aryabhata, who said the earth was not stationary. But he believed that the earth was round.

About gravity he said: "Bodies fall towards the earth as it is in the nature of the earth to attract bodies, just as it is in the nature of water to flow."

Nagarjuna

Perhaps no man in his time had more tales spun around him than Nagarjuna. He was said to be in communion with gods and goddesses, to have the power to change base metal into gold, to know the secret of making the "elixir of life." He was famous and people looked on him with awe mingled with fear.

Nagarjuna, born at Fort Daihak near Somnath in Gujarat in 931 A.D., was a chemist, rather an alchemist. If he was embarrassed by all the tales told about him, he showed no sign of it. And he only added to the popular belief that he was a messenger of God by writing his treatise, *Rasaratnakara,* in the form of dialogues between him and the gods.

Rasaratnakara dealt with preparations of *rasa* (mercury) compounds. It also gave a survey of the status of metallurgy and alchemy in the land. Extraction of metals such as silver, gold, tin and copper from their ores and their purification were also mentioned in the treatise.

To prepare the "elixir of life" and other substances from mercury, Nagarjuna made use of animal and vegetable products, apart from minerals and alkalis. To dissolve diamonds, metals and pearls, he suggested the use of vegetable acids — sour gruel and juices of fruits and plants. A list of apparatus he and earlier alchemists had used was given in the treatise. The process of distillation, liquefaction, sublimation and roasting were also mentioned.

The treatise discussed at length transmutation of metals into gold. Even if no gold could be produced, these techniques could yield metals with gold-like yellowish brilliance. Methods to prepare mercury-like substances from cinnabar and tin-like calamine were also given.

Nagarajuna also wrote *Uttaratantra* as a supplement to *Susrutasamhita,* dealing with preparation of medicinal drugs, and an *Ayurvedic* treatise, *Arogyamanjari.* His other treatises are *Kakshaputatantra, Yogasara* and *Yogasatak.*

Bhaskara

Leelavati looked entranced at the water-clock her father had brought home. Its movements were fascinating. She had a slight feeling of guilt, for her father had told her never to enter that room. But because it was forbidden territory, its exploration gave her a sense of adventure. And she continued looking at the clock.

Then came disaster, though she was never to know about it. A tiny pearl slipped out of her nose-ring and fell into the clock. She was so alarmed that she fled. And in the excitement of the arrangements being made for her wedding the next day she forgot all about the clock and the pearl. Which was not surprising for she was only six years old.

Leelavati was married, but a week later her husband fell off a cliff and died. This was what her father, Bhaskara, a great mathematician and astrologer, had feared. Astrological calculations had shown Bhaskara that, if the marriage of his daughter was not performed at a particular hour on that particular day, she would become a widow. And he had bought the water-clock to ensure that he would know the right time. He did not know that the pearl in it had made the clock inexact. And, going by that clock, he had made an error. Bhaskara thought that it was his astrological calculations that had gone wrong and blamed himself for the tragedy.

In those days, widowed girls were not allowed to marry again. Bhaskara, therefore, began to try to arouse her interest in mathematics, so that she would forget her grief. It is not known how good a mathematician she turned out to be, but he made her immortal in the history of mathematics in India by titling after his daughter a chapter of the book *Siddhantasiromani* that he wrote when he was only 30 years old. At one time there was even a popular saying: "Whosoever is well-versed with *Leelavati* can tell the exact number of leaves on a tree."

The part of the book titled *Leelavati* dealt essentially with arithmetic. The other three parts were on different aspects of mathematics: *Bijaganita* dealt with algebra, *Coladhyaya* with spheres and *Grahaganita* with planetary mathematics. Basically the book was a text-book, a collection of the works of some eminent scholars like Brahmagupta, Mahavira and Sridhara, after they had been simplified to help students. The book contained problems presented in such a way as to stimulate the student's interest. It was so popular and authoritative that four to five centuries later it was translated twice into Persian.

Bhaskara was an original thinker, too. He was the first mathematician to declare confidently that any term divided by zero is infinity and the sum of any term and infinity is infinity.

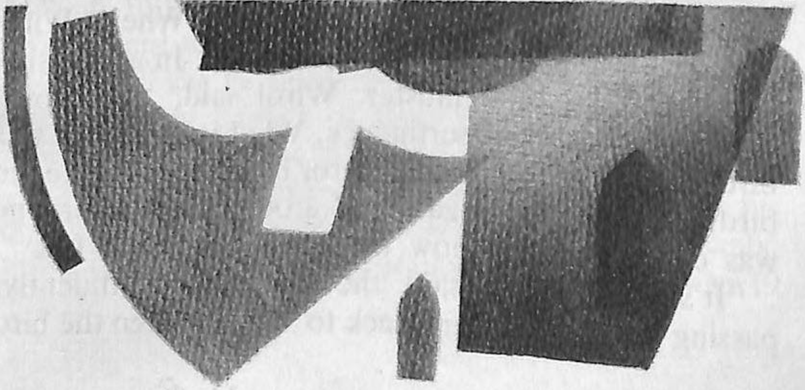
In algebra, Bhaskra considered Brahmagupta his *guru* and mostly extended Brahmagupta's work. But his introduction of *Chakrawal,* or the cyclic method, to solve algebraic equations is a remarkable contribution. It was only after six centuries that European mathematicians like Galois, Euler and Lagrange rediscovered this method and called it "inverse cyclic". Determination of the area and volume of a sphere in a rough integral calculus manner was also mentioned for the first time in his book. It contained some important formulas and theorems in trigonometry and permutation and combination.

Bhaskara can also be called the founder of differential calculus. He had conceived it several centuries before Isaac Newton and Gottfried Leibniz, who are considered in the West to be the founders of this subject. He had even given an example of what is now called "differential coefficient" and the basic idea of what is now known as "Rolle's theorem". Although Bhaskara attained such excellence in calculus, no one in the land took any notice of it.

As an astronomer Bhaskara is renowned for his concept of *Tatkalikagati,* which means instantaneous motion. This enables astronomers to determine the motion of the planets accurately.

Bhaskara was born in 1114 at Bijjada Bida (Bijapur, Karnataka) in the Sahyadri Hills. He learnt mathematics from his saintly father. Later, the works of Brahmagupta inspired him so much that he devoted himself entirely to mathematics. At the age of 69 he wrote his second book, *Karanakutuhala,* a manual of astronomical calculations. Though it is not as well known as his other book, it is still referred to in making calendars.

Royal Observations



Jahangir

Emperor Jahangir's chief huntsman, Imam Wirdi, looked in astonishment at the *safed teetar* (grey partridge) he held in his hand. He knew that the male partridge had pointed spurs on its legs and the female did not have any. But the bird he held had one spur. Whether it was male or female was, therefore, difficult to say. "An opportunity," he thought happily, "to test the Emperor's knowledge about birds. He thinks he is an expert — let's see."

The Emperor was relaxing under a shady tree after a futile hunt in the hot afternoon. When Wirdi approached him and bowed, he scowled. In as pleasing a tone as he could muster, Wirdi said, "My Lord, excuse me for my impertinence. What is the sex of this bird, My Lord?" As the Emperor began to examine the bird, all the hunters gathered around him. Everyone was eager to know how the Emperor would fare.

"It's a female," said the Emperor confidently, passing the cackling bird back to Wirdi. When the bird was killed and its stomach cut open to confirm this, some eggs were found— proof that the bird was female. Everyone, including the embarrassed Wirdi, applauded. But how had the Emperor guessed right?

The Emperor laughed. Sipping wine from his cup, he explained, "I deduced that it was female from its beak. The end of the beak is very small." Jahangir was not only a bird watcher, or ornithologist as he would be called now, but also a keen observer of animals and plants. His observations are recorded in his *Tuzuk-i-Jahangiri* (Memoirs of Jahangir).

Jahangir was born on August 30, 1569, to Akbar, the Moghul Emperor, and his Hindu wife, the daughter of Raja Bhar Mal of Amber. He was crowned on October 24, 1605. In the 22 years he was Emperor, till his death on October 28, 1627, he had many battles to fight and many rebellions to suppress. But he still found time for his hobby as a naturalist. The care and accuracy with which Jahangir described various characteristics of animals and birds, their geographical distribution and behaviour, would have done credit to a whole time naturalist. The internationally renowned Indian ornithologist, Salim Ali, says, "His memoirs are a veritable gazetteer of natural history of the India of his day."

Jahangir's detailed descriptions of birds such as the florican, dipper, hawk-cuckoo, and animals such as the polecat and monkey are notable. He made a correct estimate of the gestation period of elephants and gave details of the pairing of sarus cranes. These are his original contributions to natural science. Even until the mid-nineteenth century zoologists, unaware of his work, did not know the gestation period of elephants. Jahangir wrote that the gestation period was 18 to 19 months.

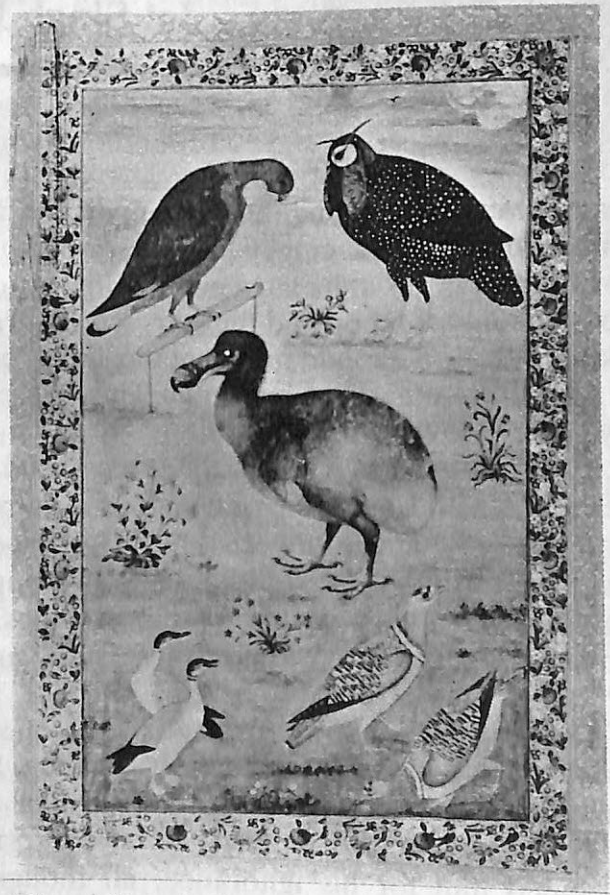
The great advantage he had was that he had a small zoo. But he had to spend hours, even nights and days, for a single observation. For the first time in the history of ornithology, he noted how sarus cranes mate, brood over their eggs in turn, and how chicks are hatched and taken care of. He also observed one human quality in this bird: the parents love not only their eggs and chicks but also each other.

Jahangir loved gardens, but his interest in botany and horticulture was superficial. His observations were mostly confined to how a lotus traps a hornet or how saffron sprouts from the soil.

He had other scientific interests. For instance, he once conducted an experiment to show that the air of Mahmudabad (Gujarat) was healthier than that of Ahmedabad. He also used to record solar and lunar eclipses. When a comet made its appearance, he recorded the growth and decay of its tail. He was also responsible for the cultivation of high altitude trees such as cypress, juniper, pine and Javanese sandals on the plains.

The Emperor had several famous painters in his court. Whenever he came across a rare animal, bird or plant, he used to summon an artist and ask him to draw it. The painter who excelled in this art was Ustad Mansur, given the title of Nadiru'l-Asr. For modern naturalists Jahangir's collection of paintings is a live catalogue. It provides a strikingly accurate description of the natural history of the day. Unfortunately, most of the paintings did not remain in the land. With the disintegration of the Moghul empire, foreign adventurers looted this treasure. Most of the portraits thus lost are those of flowers, plants and trees.

In 1958 there was sensation in the world of ornithology when a Russian researcher, A. Ivanov, discovered a portrait of the dodo, a large, non-flying pigeon-like bird which had become extinct about three centuries ago, in a collection of paintings at the Institute of Orientalists of the Soviet Academy of Sciences. There was nothing to identify the painter, but the style was without doubt of Ustad Mansur, the court painter of Jahangir. Now there is other evidence to show that it was the portrait of a Mauritius dodo which a merchant had presented to the Emperor around 1624. So, in the world of ornithology, Jahangir and the dodo made a dramatic reapperance nearly three centuries after they had died.



The extinct dodo (centre)

Sawai Jai Singh II

It was all very, very romantic. The night sky above the Amber fort, atop the craggy hills overlooking what is now Jaipur city, was at its most enchanting. And on a terrace watching the moon and the stars were a princess and a king. The princess had only that day been rescued by the king from a gang of brigands. They were both comely and in love with each other.

But, alas for romance. Though the princess did say it was heavenly, with something of a sigh of rapture, the question she asked was one that no Hollywood or Bombay film script writer would have ever thought of putting into the mouth of any of his heroines. The question was, "How far away are these stars and the moon?"

If the lover in the king was abashed by the question, so also was the astronomer in him. For the king, Sawai Jai Singh II, who had long been interested in astronomy, did not know the answer. When the princess gently chided him for his ignorance, all thoughts of romance fled and he decided that he must find the answer to her question. The princess he had rescued, a Muslim, thus set the Hindu king to a course that made him one of the greatest astronomers and mathematicians of his time.

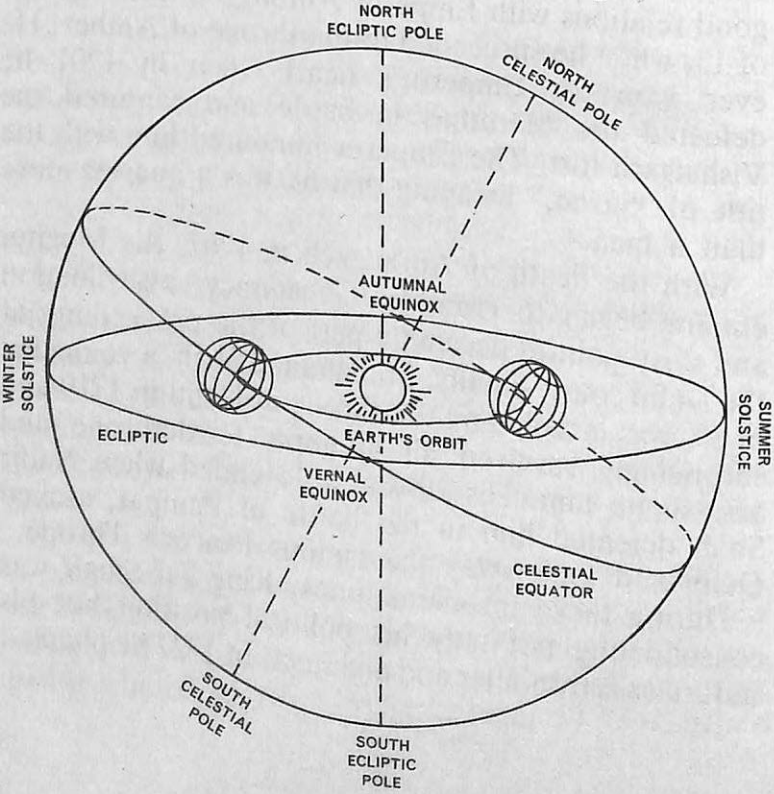
Astronomers were invited to his court for study and discussions and the king read all the treatises he could find on the subject. Although history has forgotten the name of that beautiful princess, the *Jantar Mantar* (observatories) which the king built to gain her love and admiration still stand in New Delhi, Jaipur, Varanasi and Ujjain. Unfortunately, the one at Mathura was destroyed by building contractors who wanted the stones.

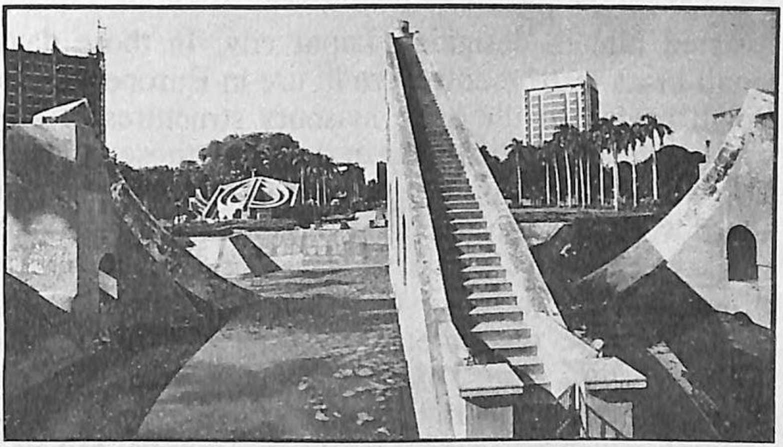
When Jai Singh was born in 1686, the Moghul Empire was about to disintegrate. He managed to keep good relations with Emperor Aurangzeb from the age of 13, when he succeeded to the throne of Amber. He even won the Emperor's heart when in 1701 he defeated the Marathas in battle and captured the Vishalgarh fort. The Emperor honoured him with the title of "Sawai," meaning that he was a quarter more than a man.

With the death of Aurangzeb in 1707, the Moghul empire began to crumble. Conspiracy, assassination and dirty politics became a part of the proceedings at the Delhi court. Finally, Muhammad Shah, a young lad of 19, was installed on the throne in Delhi in 1719 and surprisingly survived all attempts to dethrone and assassinate him. His 20-year rule ended when Nadir Shah defeated him in the battle of Panipat, sacked Delhi and took away the famous Peacock Throne.

During those turbulent times, King Jai Singh was consolidating not only his political position but his stature as astronomer and architect. In 1727 he planned and designed a new capital Jaipur (Jai's City), marvellous example of town planning and architecture. He made Pandit Jagannath, a Maratha Brahmin well versed in Persian, Sanskrit and Arabic, his *guru*. He collected astronomical treatises and tables from Portugal, Arabia and Europe. His collection included the English astronomer, John Flamsteed's *Historia Coelestis Britannica,* Pere de la Hire's *Tabulae Astronomicae,* Ulugh Beg's tables, *Zij Ulugh Begi,* and Ptolemy's *Almagest.*

He ordered the translation of these treatises into Sanskrit and gave them Sanskrit names. For instance, he called Ptolemy's treatise *Siddhantasurikaustubha,* Ulugh Beg's tables *Turusurni* and la Hire's tables *Mithiajeevachayyasurni*. He also got a telescope from Europe and even began to build telescopes.



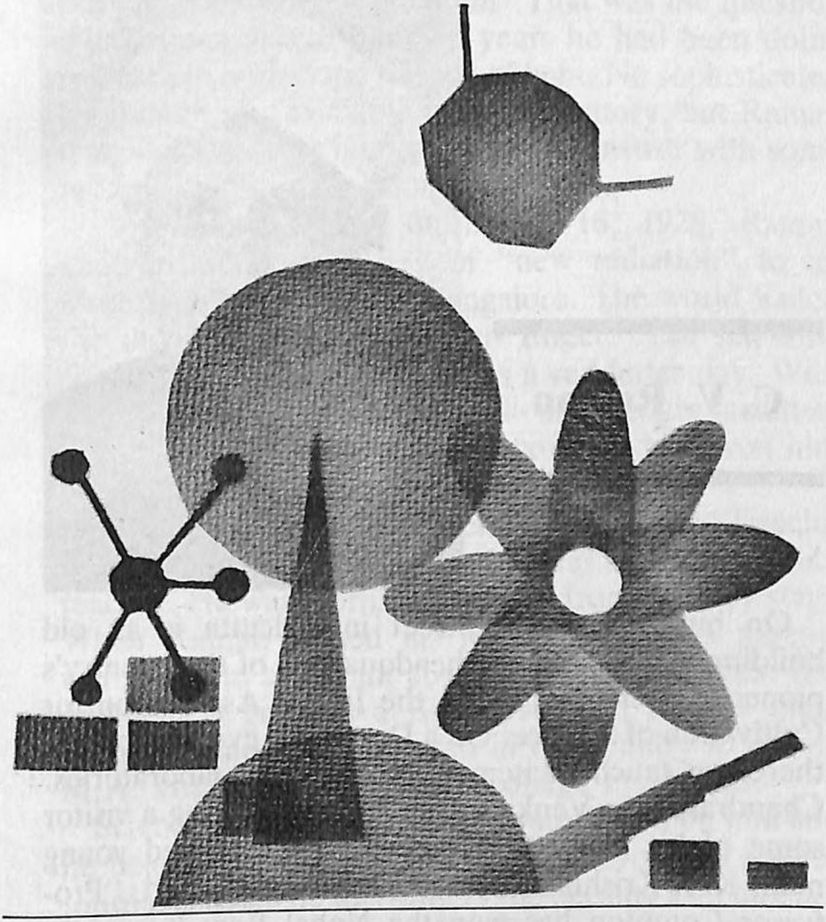


Jantar-Mantar, New Delhi

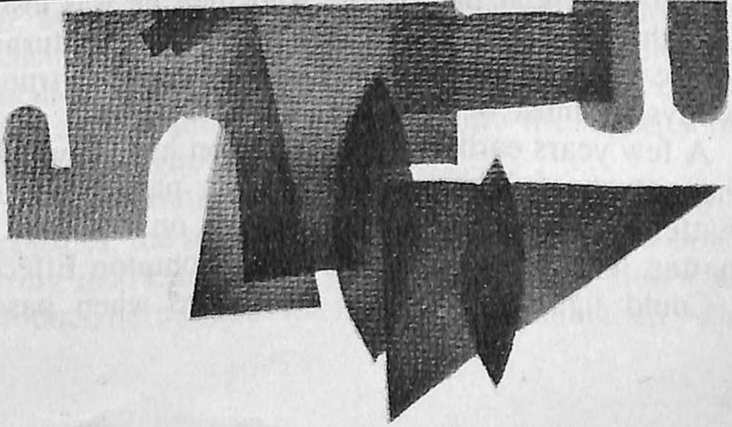
Jai Singh got the telescope late in life. His earlier observations were conducted using astrolobes and other instruments. With these he was able to detect errors in the positions of the stars and the moon given in the tables of Indian, Arab and European astronomers. Actually, the earlier astronomers were not to blame. The positions of all heavenly bodies had shifted because of a change in direction of the axis of rotation of the earth or "precession."

When Jai Singh brought the errors to the notice of Emperor Muhammad Shah and told him how they affected the timings of Hindu and Muslim religious festivals and rituals, he was asked to correct them and offered money and other help for the task. In 1724, the first *Jantar Mantar* was built in Delhi and in 1734 Jai Singh published his observations made in Delhi in the form of tables in Persian titled Zij Muhammad Shahi in honour of his patron, the Emperor.

Jantar Mantar is the distorted form of the word which in Sanskrit means "instruments and formulae." For designing these massive instruments Jai Singh consulted Pandit Vidyadhar Bhattacharya, who later also



New Frontiers



assisted him in designing Jaipur city. In those days, small brass instruments were in use in Europe, but Jai Singh preferred the huge masonry structures of lime and plaster he built similar in design to those in Ulugh Beg's huge observatory in Samarkand. He claimed that these were far more accurate. He made his observatories available to anyone who wanted to study astronomy, hoping to make the science popular.

Among the instruments he designed himself are *Samrat Yantra, Ram Yantra,* and *Jai Prakash*. The first is basically a huge right-angled gnomon, a kind of sundial, which measures time to an accuracy of half a minute. It is also used to determine the altitude of the sun and the positions of equinoxes and solstices. The *Ram Yantra,* a tall pillar inside a graduated cylinder, measures the altitude and azimuth of heavenly bodies to a high degree of accuracy.

The most original of all is the *Jai Prakash,* a wide concave bowl on which the positions of all heavenly bodies can be mapped round the clock.

Jai Singh made two fundamental contributions to astronomy. One is the measurement of the precession of the equinoxes and the other the obliquity of the ecliptic. His findings are far more accurate than those of his predecessors like Ptolemy and Ulugh Beg.

Surprisingly, Jai Singh confined himself to observation. He never gave thought to whether the earth moves round the sun or vice versa. He accepted Ptolemy's geocentric concept of the universe. Copernicus's heliocentric concept, which claims that the sun is at the centre, and all the planets, including the earth, move round it, a widely accepted view then in Europe, made no impression on him. It is possible that he deliberately ignored the Copernicus concept fearing that his support to it would upset the priests.

C. V. Raman

On busy Bowbazar Street in Calcutta is an old building at 210. It is the headquarters of the country's pioneering scientific body, the Indian Association for the Cultivation of Science. On a December evening in 1927 there was much excitement in one of its laboratories. Chandrasekhar Venkata Raman was showing a visitor some of his instruments when a bespectacled young man, K.S. Krishnan, rushed in and announced, "Professor Compton has won the Nobel Prize."

Raman was equally delighted. "Excellent news," he said, beaming at the visitor. And then he was lost in thought. "But...look here, Krishnan," he said turning to the young man, "if this Compton effect is true of X-rays, it must be true of light too."

A few years earlier, A.H. Compton had shown that the nature of X-rays changes when passed through matter. The change was dependent on the kind of matter. This effect was called the "Compton Effect."

Could light also change its nature when passed through a transparent medium? That was the question that Raman asked. For five years he had been doing research in optics, the science of light. No sophisticated equipment was available in his laboratory, but Raman was confident that he could find the answer with some modifications in his equipment.

Four months later, on March 16, 1928, Raman announced his discovery of "new radiation" to an assembly of scientists at Bangalore. The world hailed the discovery as the "Raman Effect." For scientific research in this country, it was a red letter day. With equipment worth hardly Rs 200/- and meagre facilities, Raman was able to make a discovery which won him the 1930 Nobel Prize in physics.

Raman was born on November 7, 1888, at Tiruchirapalli in Tamil Nadu. His father was a college physics teacher. He was a brilliant student from the very start. When Raman passed his matriculation, his parents were keen to send him abroad for higher studies. But on medical grounds a British surgeon advised them against it and Raman stayed in the country to do the M.A. course at Presidency College in Madras.

Science had already made an impression on him and he began to write research papers for reputed science journals. When he was only 19, he became a member of the Indian Association for Cultivation of Science. Meanwhile, respecting his parents' wishes, he took up an administrative job in the Finance Ministry in Calcutta. His interest in science, however, did not flag. He used to spend his hours after office in the laboratory of the association, working late into the night, sometimes throughout the night.

In his youth, Raman was mainly interested in acoustics, the science of sound. He studied how bowed string instruments like the violin and the sitar could produce harmonious music. He was so taken up with it that after he finished a lecture on the acoustics of the violin, a scientist in the audience jocularly asked him whether he wanted to become Fellow of the Royal Society by fiddling in physics. That was in London in 1921 and it set him thinking.

On his return journey aboard a liner the blueness of the sky and the sea intrigued him. Why were they blue? Sitting on the deck of the ship, he sought the answer. And he came to the conclusion that the blueness was due to the scattering of light by water molecules. This intuition had to be tested. On his return to his laboratory in Calcutta he lost no time trying to prove the theory. Thus began his research in optics that was to make him famous.

In 1924 Raman was elected Fellow of the Royal Society for his contributions to optics. Six years later, when he was awarded the Nobel Prize, he won world acclaim.

In 1943, he founded his own institute near Bangalore, the Raman Research Institute, a palatial building set in the midst of gardens and trees. Here he continued to work till his death on November 20, 1970.

Raman never lost his interest in acoustics and one of his significant discoveries is that the *mridangam* and the *tabla,* unlike other drums, possess harmonic overtones.

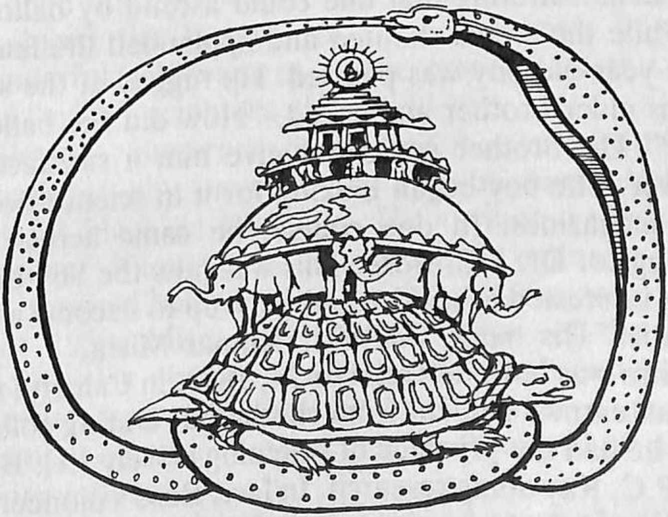
In his later days, anything that was colourful, whether it was a butterfly, gem or flower, fascinated him. He was ever asking questions. Why do things look beautiful? What makes gems and stones bright and colourful? And he was ever trying to find the answers.

His advice to young scientists was also to look at the world around them and not to confine themselves to their laboratories. "The essence of science," he said, "is independent thinking and hard work, not equipment."

"The Raman Effect" is the phenomenon that causes changes in the nature of light when it is passed through a transparent medium, whether solid, liquid or gaseous. The phenomenon takes place when molecules of the medium scatter light energy particles, "photons," just as a striker scatters a bunch of coins on a carrom board. From the minute changes observed in the energy of the photons, or nature of light, the internal molecular structure of the medium can be deduced.

The "Raman Effect" is important in understanding the molecular structure of chemical compounds. In fact, within a decade of its discovery, the internal structures of some 2,000 chemical compounds were determined. Subsequently, the internal structures of crystals were also determined.

With the invention of the "laser", with its powerful light radiation, the "Raman Effect" has become a powerful tool for scientists.



S. K. Mitra

A shot was fired and a huge balloon rose up, carrying a man with it. The assembled crowd at the Calcutta Maidan cheered. The man, Ram Chandra Chatterjee, was demonstrating that one could ascend by balloon.

While the crowd shouted and applauded the feat, a nine-year-old boy was puzzled. He tugged at the shirt of his elder brother and asked, "How did the balloon rise?" His brother could not give him a satisfactory answer. The boy began looking for it in science books and magazines. In due course, he came across the writings of Dr. J.C. Bose. This was how the boy came to be interested in science and grew up to become a top scientist. His name was Sisir Kumar Mitra.

Mitra was born on October 24, 1890, in Calcutta and was an earnest student from childhood. During college days he had the privilege of watching closely J.C. Bose and P.C. Ray doing research. In fact, Bose's pioneering equipment for generating and detecting radio waves influenced him to take up research in radio science.

Later, when he realised the importance of this newborn science in communication, he introduced it in the country. Thanks to his untiring efforts, the subject gained importance in Indian universities. The radio industry was started in the country. The Haringhata Ionosphere Field Station was installed and the Institute of Radio Physics and Electronics founded in Calcutta.

In the scientific world Mitra is renowned for his contributions to the study of the ionosphere. The ionosphere is a layer containing electrically charged particles called "ions" in the upper atmosphere which reflects radio waves like a mirror. When a radio or television station transmits a radio wave, this layer reflects it back to the earth and our radio or television set receives it. The study of the ionosphere is, therefore, vital for radio communication.

The ionosphere is composed of several layers designated as D, E, F and so on depending upon height and property. On the basis of his investigations, Mitra claimed that ultra-violet radiations emitted by the sun produced the E layer of the ionosphere. It was a wonderful achievement as the presence of this layer had baffled scientists the world over.

Besides numerous other contributions, Mitra also found out why the night sky appears dusty black and not jet black as it should. He attributed this to the presence of ions in the F layer, which emit some light, the process being called "night sky luminescence".

In 1958, Mitra was elected Fellow of the Royal Society. He also received several awards and medals. In 1947 he wrote *The Upper Atmosphere*, the first treatise on the subject which received worldwide appreciation.

He died at the age of 73 on August 13, 1963.

M. N. Saha

In 1905, when the British Government divided Bengal into East and West, the people were outraged. No one more than a 12-year-old schoolboy, Meghnad Saha. He was too young to join the band of revolutionaries formed to fight for Bengal's unity. So he had to find some other way of protest. His opportunity came when it was announced that the British Governor of Bengal was to visit his school. Despite the stern warning that everyone should be present to greet the Governor, he and some of his friends boycotted school on the day the Governor arrived.

The next day, the names of Saha and his friends were struck off the rolls of the school. Saha had to pay a heavier price than the rest as he lost the scholarship he had won only a few months earlier. This spirit of nationalism and self-sacrifice was evident right through his life, even when he became a well known scientist. The patriot in him made him a nation-builder too. He not only tried to raise the status of science in independent India, but also served the cause of the poor.

Saha was born in Seoratali, Dacca district, now in Bangladesh, on October 6, 1893. His father was a petty grocer who barely managed to keep his large family from starvation. He wanted his fifth child, Meghnad, to start earning for the family from childhood. But on the advice of local teachers, who found him a brilliant student, the grocer allowed the boy to join a boarding school eleven kilometers from the village with a well-wisher paying his fees and other charges.

When Saha secured a scholarship, he was sent to Dacca for higher studies. After the boycott, he had to join another school. However, in the final examinations he stood first. Again winning a scholarship he joined Presidency College, Calcutta. Here he was not only taught by eminent teachers like J. C. Bose and P. C. Ray but had brilliant contemporaries like S. N. Bose and P. C. Mahalanobis, who, like him, became noted scientists in due course.

Saha secured the second position in M.Sc. (the first position went to S. N. Bose) and decided to join the Indian Finance Service as he wanted to help his needy family. Fortunately for scientific research in the country, his earlier school boycott and association with nationalists like Subhash Chandra Bose and Rajendra Prasad stood in his way and he was not allowed to take up any government job. Naturally, he turned to his first love—research in physics and mathematics.

He earned his living by giving tuition, cycling to distant places, morning and evening, to teach his students physics and mathematics. In 1917, he and S. N. Bose were appointed lecturers at the newly opened University College of Science in Calcutta. Thermodynamics, relativity and atomic theories were then the latest developments in physics and Saha read books on these subjects avidly and taught them as well. It was while preparing his lecture notes that he came across an astrophysical problem, the solution of which made him world famous.

Astrophysics deals with the nature of the stars, their temperature, internal structure and composition. Reading Agnes Clark's books on the sun and the stars, Saha found the problem that intrigued him. Just as sunlight passing through suspended rain drops produces the rainbow, a band of colours, called "spectrum", is produced when sunlight passes through a glass prism. With the band of colours are dark and bright lines of varying thickness in the spectrum, called "spectral lines". Gustave Robert Kirchoff had shown that these spectral lines told the elemental composition of the sun, but astronomers could not make out what caused them.

Aware of the latest advances in physics, Saha put forward an "ionisation formula" which explained the presence of the spectral lines. The formula also enabled an astronomer to know the temperature, pressure and other aspects of the interior of the sun or any other star. The formula proved to be a breakthrough in astrophysics.

Saha was hardly 25 then. The scientific world applauded his work. One eminent astronomer even called it the twelfth major discovery in astrophysics.

In 1927, almost a decade after his discovery, Saha was elected Fellow of the Royal Society. Till then not many of his countrymen had known him or his work. And some scientists had even gone to the extent of calling his formula a fake and made efforts to stop him from joining the physics department of Allahabad University.

Saha was, however, an *eigenschaften*, an invincible person, a name he had acquired because of his tenacity of purpose. He did not care what others said of him and went on doing his research and teaching.

In Allahabad he began research in spectroscopy, the study of the spectrum and ionosphere, and thus raised the department to international status.

Ancient Indian history, geology and archaeology also attracted his attention. He studied the origin of the Saka era and measured the age of some rocks. Later, when he moved to Calcutta, he did research in radio waves from the sun and radioactivity.

When Otto Hahn, the father of the atom bomb, discovered "fission" in 1940, Saha immediately recognised its importance. On his initiative nuclear physics was taught for the first time in the country at Calcutta University. In 1948 he founded what is today known as the Saha Institute of Nuclear Physics in Calcutta. Having seen cyclotrons used for research in nuclear physics abroad, he ordered one to be installed in the institute. In 1950, India had its first cyclotron in operation.

Saha was also a social worker. Having suffered poverty himself, he did not forget his poor countrymen. When the partition of India took place and refugees from East Bengal (now Bangladesh) poured into the country, he did much to resettle them. He also did not forget the relief work he had done in his childhood when the river near his house used to overflow its banks during the monsoon. He studied the origin and control of floods and suggested a number of river valley projects. The Damodar Valley, Bhakra-Nangal and Hirakud projects are the final products of the work that he started.

Saha was fearless and frank in his criticism of some governmental policies. He had full faith in industrialisation and was against the "back to the village movement", which, he claimed, would not solve the problems of poverty, disease and ignorance. He founded a magazine, *Science & Culture*, to put forward his views. In 1952 he stood as an independent candidate for Parliament and was elected by a wide margin. He died on February 16, 1956.

S. N. Bose

When that great educationist, Asutosh Mookerjee, founded the University College of Science in Calcutta, it did not have even a proper library. So, when in 1916 two brilliant young men joined the college as lecturers, with ambitions of doing research in physics and mathematics, they were greatly disappointed.

Those were the days when a revolution was taking place in physics. What we today call "modern physics" was emerging. The German physicist, Max Planck, had propounded the quantum theory, that energy is released only in extremely small packets. And Albert

Einstein had propounded his theory of relativity. Besides, big strides were being made in understanding the interior of the atom. Although other lecturers were satisfied with teaching the "old" physics, the two young men were eager to know the advances made in modern physics.

That was hard. With World War I still on, the latest books and journals were not reaching the country. In desperation the two began to hunt for books. Visits to nearby schools and colleges proved futile, but their efforts eventually paid. A German scientist, P.J. Bruhl, who was staying in the country, had some books and papers on modern physics. But they were in German.

The two scientists were, however, persistent in their quest for knowledge. They learnt German. And it was not long before students and teachers found them discussing and debating between themselves the new findings in modern physics. What was even more wonderful was that they began to teach relativity to their students, till then not attempted elsewhere. In 1920, they translated Einstein's papers on relativity from German into English, the first physicists to do so.

The two young men were none other than Satyendra Nath Bose and Meghnad Saha. For some time they did research together. Then Saha went abroad and Bose moved to Dacca University.

This was a turning point in Bose's life. One of his friends, who had just returned from abroad, presented him with a copy of Max Planck's famous *Thermodynamik und Warmestrahlung* (Thermodynamics and Heat). The book contained all the original papers of the great physicist. As Bose read it he solved the equations and formulae himself.

At one place, however, he was stuck. Planck had assumed some hypothesis and calculated an equation approximately. "Never accept an idea as long as you yourself are not satisfied", was Bose's motto. He, therefore, began to work out a better way and, in the process, created a landmark in the development of theoretical or mathematical physics. He was then hardly 30.

Bose sent his four-page research paper, *Planck's Law and Light Quantum Hypothesis* to an Indian journal and subsequently to several abroad. All of them rejected it. After all, who could have dreamt that an Indian working in a then obscure university could produce a revolutionary work?

In desperation, in 1924 Bose sent his paper to Albert Einstein. Bose had put forward a daring concept in the paper, which impressed Einstein so much that he himself translated the paper into German and got it published in a German journal, *Zeitschrift fuer Physik*. He also added his comment: "An important forward step".

Bose's paper played a big role in the development of a new type of statistics. The statistics that he worked out to explain the behaviour of radiation is called "Bose statistics". Elementary particles such as photons and alpha particles which obey "Bose statistics" are called "Bosons". His name has thus become a part of science.

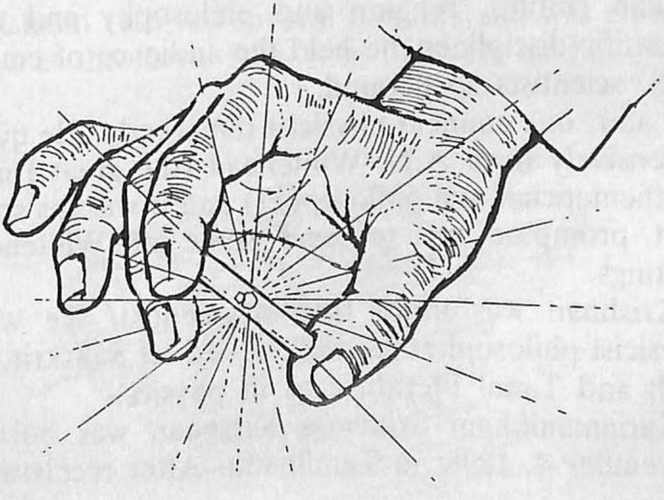
Bose was born on January 1, 1894. That he would one day become a great mathematician like Pierre Simon Laplace and Augustin Louis Cauchy was not doubted even when he was in school. His skill at solving questions used to impress his teachers so much that they used to award him 110 marks out of 100! In fact, they were always afraid of his tricky questions.

But, international recognition eluded him. It was late in life, 34 years after his significant discovery, that he was elected Fellow of the Royal Society. In fact, on several occasions, he had to take testimonials from famous physicists like Albert Einstein to convince the authorities of the worth of his work.

Unlike many scientists, Bose was gregarious. He would chat for hours with friends and students and could talk on almost any subject — from the price of fish to the latest problems in physics. He realised the importance of bringing science to the masses and urged scientists to write in their mother tongue. He founded an association and a popular science magazine in Bengali.

Bose is also renowned for his experimental work in such branches of physics as X-ray crystallography and thermoluminescence. He produced a new chemical compound which is even today used as an eye-drop.

At an international seminar held in Calcutta to mark the golden jubilee of his discovery of "Bose statistics", Bose said that he had no desire to live any longer as his work was being recognised the world over. Only a month later, on February 4, 1974, he died, leaving a half-finished problem relating to the theory of numbers on his table.



K. S. Krishnan

In 1955 the U.S. National Academy of Sciences invited K.S. Krishnan to be guest speaker at its annual dinner–a rare privilege for any scientist. And Krishnan more than fulfilled expectations. He talked about the change India would bring about in her culture using science and technology. With his deep knowledge of Indian culture, religion and philosophy and many scientific disciplines, he held the audience of eminent U.S. scientists spellbound.

Later, one eminent physicist remarked, "He quoted extensively from A.N. Whitehead (the great English mathematician and philosopher) and it was his speech that prompted me to read some of Whitehead's writings."

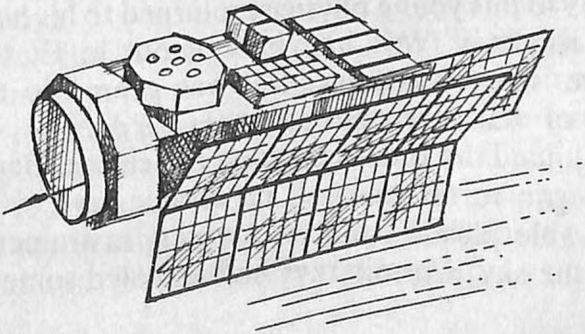
Krishnan was more than a scientist. He was a physicist-philosopher as well versed in Sanskrit, English and Tamil literature as in physics.

Kariamanikkam Srinivasa Krishnan was born on December 4, 1898, in Tamilnadu. After receiving his basic education in Madras, he went to Calcutta in 1920 to do research. Here he joined the Indian Association for Cultivation of Science to work under C.V. Raman in the field of optics. It is said that he was partly responsible for the discovery of the "Raman Effect." In 1948, he became the first Director of the National Physical Laboratory in New Delhi.

"Physics means facing facts," Krishnan always told his students. His contributions to physics are in diverse fields. Everyone must have seen the beautiful, regular pattern in crystals. The pattern is due to the arrangement of atoms or molecules. Different patterns arise from different arrangements. Solid state physics is the study of such arrangements in any solid and the various phenomena occuring in them. Krishnan studied the fine arrangements in various solids and the forces between atoms or molecules that keep them so.

Another subject to which he made significant contributions is thermionics, the study of electrons emitted by a hot body, their behaviour and control. He also studied how heat is distributed in solids of various shapes, namely rods and coils, when heated in a vacuum. This has wide industrial applications.

Krishnan received several honours and was elected Fellow of the Royal Society in 1940. He died in 1961.



H. J. Bhabha

Cosmic rays are fast-moving, extremely small particles coming from outer space. When these particles enter the earth's atmosphere, they collide with the atoms in the air and produce showers of electrons. In 1937, Homi Jehangir Bhabha, an Indian physicist, and W. Heitler, a German physicist, solved the mystery surrounding these rays and became world famous.

Bhabha went a step further. He recognised the presence of a new nuclear particle in the showers, which he called "meson". In this particle he also found experimental proof of Einstein's theory of relativity.

In 1940 this young physicist returned to his homeland from England. War had broken out in Europe and science, like everything else, was geared to the purposes of war and destruction.

He joined the Indian Institute of Science, Bangalore, and began to do research on cosmic rays, with huge retrievable plastic balloons carrying instruments high up in the sky. Cosmic rays had revealed some revolutionary facts about the nature of matter and research, he thought, might reveal still more on this subject. And, if research in cosmic rays could be taken up in the country, Indian scientists could, within a short time, be in the forefront in physics. Modern techniques in nuclear, high energy and elementary particle physics could also be developed in the country. He wanted to have an institute exclusively devoted to research in this field.

Meanwhile, Bhabha was elected Fellow of the Royal Society for his contributions relating to cosmic rays, elementary particles and quantum mechanics. His voice commanded attention and all scientists supported his idea of building a research institute. Bhabha was related to the Tatas, the country's pioneering industrialists. In 1944 he wrote a letter to the Tata Trustees urging them to build an institute. He argued that the country would not then have to look abroad for experts when nuclear plants for electric power generation came to be built. While other scientists were trying to tap energy from the atom for destructive purposes, he was thinking of its peaceful uses.

In 1945, the Tata Institute of Fundamental Research was set up. Two years later, when the country gained independence, his ideals gained more significance. Jawaharlal Nehru, the first Prime Minister, also wanted to make the country self-sufficient in science and technology and he gave Bhabha a free hand to do what he wanted.

In 1948 the Atomic Energy Commission was set up and Bhabha made its Chairman. From then on, nuclear energy research has steadily gathered momentum in the country. Under the expert guidance of Bhabha, three atomic reactors, Apsara, Cirus and Zerlina, were built. Survey for uranium ore continued and plants to purify the required materials were also built.

Construction of the country's first atomic power station began at Tarapur in 1963. Two years later a plutonium plant was installed, which was hailed as a "great step". In short, Bhabha showed his countrymen and the world that Indians were second to none in gaining scientific knowhow. The climax came on May 18, 1974, when Indian scientists exploded a nuclear device for peaceful purpose at Pokhran in Rajasthan. India became the sixth country to join the nuclear club.

Bhabha also encouraged research in electronics, space science, radio astronomy and microbiology. The radio telescope at Ootacamund is one of his creations. He was also one of the eminent members of the "atom for peace" conference. It was during one of his visits abroad that he died in a plane crash at the age of 57. The nation mourned his sudden death. In 1967, the Atomic Energy Establishment, Trombay, was renamed the Bhabha Atomic Research Centre as a tribute to his dedication and work.

Bhabha was born on October 30, 1909, into a wealthy Parsi family. He had a good library of science books at home and even as a child was interested in science. He used to spend his spare time painting and writing poetry. He was also fond of music, particularly the Western classics. His father's ambition was to train Bhabha as an engineer and he was sent abroad for higher studies. However, his interest shifted to physics. During his studies abroad he won many medals and fellowships. He also got the opportunity to work with eminent physicists like Enrico Fermi and Wolfgang Pauli.

Bhabha was a bachelor. He used to say that he was "married to creativity". He was a first class painter. His pencil sketches are well known and some of his paintings are preserved in British art galleries. He was a man of refined taste and this was very evident whether it was in the choice of design for the building of the Tata Institute of Fundamental Research or the site for the Ooty radio telescope.

V. A. Sarabhai

In 1943, Vikram A. Sarabhai, who was then hardly 23, went to the Himalayas in Kashmir to study cosmic rays at high altitude. He was so thrilled that he decided to set up a laboratory to study cosmic rays.

On his return from the United Kingdom with a Ph.D., he founded the Physical Research Laboratory in Ahmedabad, an institution devoted to the study of cosmic rays and outer space. In 1955, he set up a branch of the laboratory at Gulmarg in Kashmir. He also set up other branches in Trivandrum and Kodaikanal.

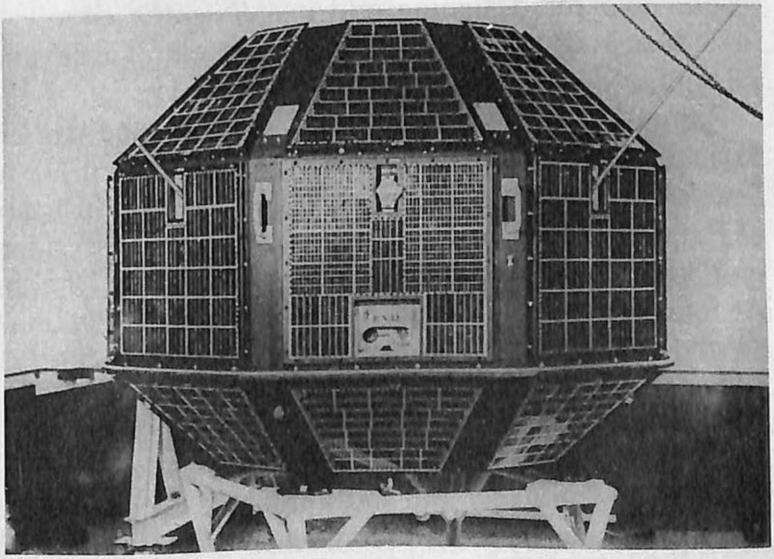
Sarabhai was born on August 12, 1919, and his life was similar to Bhabha's. He, too, belonged to a wealthy family. Had he wished, he could have become an industrialist, but his basic interest was in mathematics and physics. The purpose of the Physical Research Laboratory that he founded was similar to Bhabha's creation, the Tata Institute of Fundamental Research. It provides the technology and scientists needed for the country's space programmes, just as the Tata Institute of Fundamental Research provides these for its nuclear programme.

In fact, Sarabhai ushered in the space age in the country by expanding the Indian Space Research Organisation. The credit for much of what India achieved in space technology must go to him, though he did not live to see many of the fruits of his labour. Among the projects he planned was the one under which India's first satellite, Aryabhata, was launched in 1975. The Satellite Instructional Television Experiment (SITE) in 1975-76, which sought to bring education to five million people in 2,400 Indian villages, also owes much to Sarabhai.

Although Sarabhai was busy with space programmes, he did not forget his first love—the study of cosmic rays. His basic interest was to find out how the rays vary with time and the implications of this phenomenon. Cosmic rays are a stream of energy particles reaching the earth from outer space. On their way to the earth they are influenced by the sun, the atmosphere and magnetism. Events taking place in space among the planets also affect these rays. At an early age Sarabhai realised that the study of cosmic rays would help in understanding terrestrial magnetism and the atmosphere, the nature of the sun and outer space. Most of his research was confined to this aspect of the rays.

In one respect Sarabhai went a step ahead of Bhabha. He built a variety of institutions—one devoted to modernisation of the textile industry, another to development of management skills and yet another to popularising science, apart from the Physical Research Laboratory and the Indian Space Research Institute.

Like Bhabha he died at an early age, when he was only 52. He received many honours and awards for his services to science and society. The International Astronomical Union named after him a crater on the moon in the Sea of Serenity.



Aryabhata satellite

Raja Ramanna

On May 18, 1974, India tested its first nuclear device in the Pokhran desert in Rajasthan. The credit for this achievement goes to Raja Ramanna and his colleagues, as also to Bhabha, who laid the foundation for the country's nuclear programme. This was, however, not Ramanna's first success. He was also the man mainly responsible for designing and installing the country's first series of nuclear reactors, Apsara, Cirus and Purnima.

Ramanna was born on January 28, 1925, and had his basic education at Bangalore. He did his Ph.D. at London University. In 1949 he joined the Tata Institute of Fundamental Research as professor and subsequently headed the Nuclear Physics Division of the Bhabha Atomic Research Centre. In 1966, after Bhabha's death, he took over the task of building the country's nuclear power potential.

The Pokhran nuclear test was Ramanna's idea. Dynamite is generally used to dig canals and reservoirs, clear space for dams and harbours and even to make underground storehouses for nuclear wastes. For such purposes nuclear energy is not used because the explosion not only produces harmful radioactive fall-out, but is also violent.

Ramanna thought of an underground nuclear test to find out how it would fare in place of dynamite. According to his estimation, the test has shown that nuclear energy can be tamed without any ill-effects. In addition, it will be cheaper than dynamite in the long run. The test was indeed a big step forward in using nuclear energy for peaceful goals.

Ramanna's fundamental contributions lie in the field of nuclear fission. He put forward a new theory to explain how heavy nuclei split and generate energetic nuclear radiation.

Besides nuclear physics, he is keenly interested in ancient Indian philosophy.

M. G. K. Menon

Mambillikalathil Govind Kumar Menon, a renowned physicist, learned the "beauty of the scientific method and its application to a wide spectrum of human endeavour" from his Nobel Laureate *guru,* C.F. Powell. From his mentor, H. J. Bhabha, he learned how "first class research is possible in a country like India by good planning and organisation and by careful selection of the area of work".

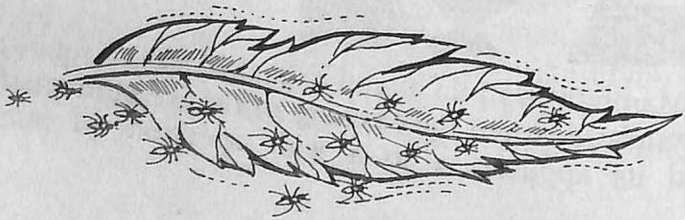
He has thus brought the country to the frontline of scientific fields such as electronics and cosmic ray physics. As a science administrator, which a developing country like India needs, he is doing yeoman service to the Indian scientific community and the country as a whole.

Menon was born on August 28, 1928, to a District and Sessions Judge at Mangalore in Karnataka. After his basic education in different parts of the country he joined the University of Bristol in the U.K. in 1949. There he did research under C. F. Powell and discovered a few "elementary particles". They included muons of varying energies, K-particles and a specific category of pions.

In 1955 he returned home and joined the Tata Institute of Fundamental Research. Here he conducted studies on cosmic rays at high altitudes over India close to the geomagnetic equator and at great depth below the ground at the Kolar gold mines.

Menon received several awards and honours. In 1960 he won the S. S. Bhatnagar Award and in 1970 was elected Fellow of the Royal Society. Apart from research, he loves painting, sculpture and gardening.

Early in 1986 he was appointed Scientific Advisor to the Prime Minister.



J. V. Narlikar

How did the universe, which is composed of stars, galaxies, nebulae, come into being? Philosophers and scientists have been pondering over this question for centuries.

Most scientists now believe that the universe came into being when a highly dense, atom-sized body exploded with a bang. Like a cracker the body threw away matter which later formed the stars, galaxies, nebulae and so on. This is called the "big bang" theory.

There is, however, one Indian astrophysicist, Jayant Vishnu Narlikar, who does not believe that a firm case has yet been made for this theory. In fact, at one time he was a firm believer in the rival "steady state" theory.

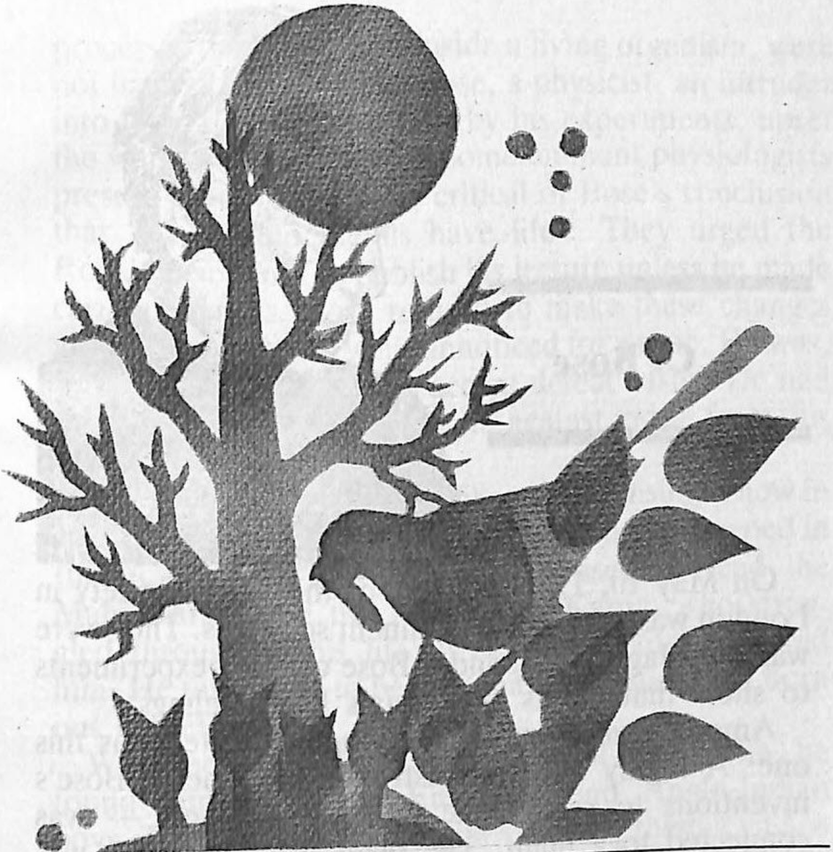
According to this theory the universe remains the same at all times, past, present or future. Matter in the form of stars, galaxies and other bodies is uniformly distributed all over the universe. New matter is created to fill any gap that arises because of the motion of a galaxy or other bodies.

Apart from his work on the "steady state" theory, Narlikar worked in collaboration with his teacher, Fred Hoyle, on a new theory of gravitation, when he was hardly 26. The theory was then considered to be a breakthrough as significant as Einstein's theory of relativity. In fact, the world hailed Narlikar as India's Einstein.

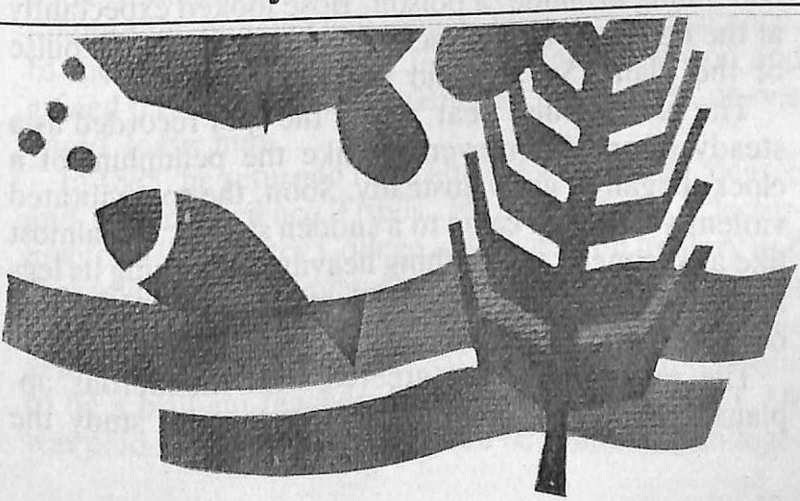
Narlikar belongs to a family of mathematicians. He was born on July 19, 1938, at Kolhapur, Maharashtra, but was brought up in Varanasi in the house of his uncle, a mathematician. Every morning the uncle would write a mathematics problem on a blackboard and it would not be rubbed off until young Jayant had solved it. After doing his M.Sc. and Ph.D. from Banaras Hindu University, Narlikar went to Cambridge to do research under Fred Hoyle at King's College. For his research work in astronomy he received several awards, medals and scholarships.

Narlikar returned home in 1972 and since then he has been Professor of Astrophysics at the Tata Institute of Fundamental Research. He is now working with his students on tachyons, which are faster than light particles, and "black holes", highly contracted heavenly bodies of immense gravity. One spoonful of a "black hole" weighs as much as several tons and so it does not allow even light to escape from its surface. According to Narlikar, a "black hole" can absorb tachyons and reduce its own surface area. Therefore, one way to detect tachyons, he claims, is to look for "black holes" which are reducing in size.

Narlikar has worked hard to make science popular and is a science fiction writer.



Mysteries of Life



J. C. Bose

On May 10, 1901, the hall of the Royal Society in London was packed with eminent scientists. They were watching Jagadish Chandra Bose conduct experiments to show that plants and metals have feelings.

Among several experiments he conducted was this one: A highly sensitive instrument — one of Bose's inventions to record the "pulse" of plants — was connected to a plant. The plant, with its roots, was carefully picked up and dipped up to its stem in a vessel containing bromide, a poison. Bose looked expectantly at the light spot on a screen meant to indicate the pulse of the plant. So also did everyone else.

The plant's pulse beat, which the spot recorded as a steady to-and-fro movement like the pendulum of a clock, began to grow unsteady. Soon, the spot vibrated violently and then came to a sudden stop. It was almost like a poisoned rat breathing heavily and jerking its legs and tail in its struggle against death. The plant had died because of the poison.

The experiment was greeted with thunderous applause. However, some physiologists, who study the processes that take place inside a living organism, were not happy. Not only was Bose, a physicist, an intruder into their field, but he had, by his experiments, upset the well-known theories of some eminent physiologists present there. They were critical of Bose's conclusion that "plants and metals have life". They urged the Royal Society not to publish his lecture unless he made certain changes. Bose refused to make these changes and his experiments went unnoticed for a time. He was, however, not a person to accept defeat easily. He had acquired the quality to fight against odds from his childhood.

Born on November 30, 1858, at Mymensingh, now in Bangladesh, Bose was brought up in a home steeped in Indian tradition and culture. He used to read the Mahabharata and the Ramayana. Karna, who struggled throughout his life to achieve success, inspired him. He thus came to believe that "true success is born out of defeat".

When he joined St. Xavier's School in Calcutta, he found himself among European and Anglo-Indian boys. They were amused to have among them a village boy. One of them was a champion boxer, who tried to bully young Jagadish. One day, Jagadish, unable to tolerate the bullying any longer, took up the challenge. In the fight that followed Jagadish somehow won and gained the respect of his classmates. Thereafter, no one dared tease him.

In 1885, he returned from abroad with a B.Sc. degree and Natural Science Tripos. He was offered a lecturership at Presidency College in Calcutta on a salary half that of his "white" colleagues. He accepted the job, but refused to draw his salary as a protest. After three years, when the college Principal, a Briton, found him to be a brilliant teacher, he conceded his demand. He was paid full salary from the date he joined the college.

Bose had thus learned the hard way to fight for justice. So, when physiologists of the Royal Society criticised him, he took up the challenge. And he won. After two years of rigorous research he published a monograph, "Response in the Living and Non-living", which convinced the Royal Society that he was right. His lecture, which was earlier withheld from publication, was published and circulated all over the world. Bose became a world famous scientist. Research in the field of plant physiology was gradually taken up in various countries. Apart from several other honours, he was elected Fellow of the Royal Society in 1920.

It was on his 36th birthday that Bose decided to devote himself to pure research. Oliver Lodge's paper on Heinrich Hertz and his successors had inspired him so much that he began to conduct research on what is today known as "radio waves". Although he did not get any facility or money from the college, he made the equipment he needed within three months and embarked upon his research. The training in metal turning and carpentry that he had received in his teens came in handy. Later, this very training enabled him to fabricate many sensitive instruments for plant studies.

Although Bose is more famous as a biologist, he was a great physicist as well. He can rightly be called the inventor of wireless telegraphy. In 1895, a year before Guglielmo Marconi patented this invention, he had demonstrated its functioning in public. He was the first to fabricate the device that generated microwaves — radio waves of very short wavelength. Also, he was the first to use these microwaves to understand the structure of materials. One of the devices he had fabricated, now called the "wave guide", forms an essential component of several sophisticated electronic and nuclear equipment.

Bose also fabricated a highly sensitive "coherer", the device that detects radio waves. In fact, it was thanks to his detailed research on it that he switched from physics to the study of metals and then plants. He found that the sensitivity of the coherer decreased when it was used continuously for a long period. In other words, it became tired. And, indeed, when he gave the device some rest, it regained its sensitivity, which clearly indicated that metals have feelings and memory. The metals that are used daily, such as a knife, are not dead but unconscious, like a badly beaten man. They enter this state when they are heated and moulded.

Bose also invented several sensitive instruments. The most wonderful was the crescograph, an instrument to measure the rate of growth of a plant. How sensitive this instrument was can be imagined from the fact that it could measure plant growth that was 20,000 times less than snail's speed.

Bose arrived at the conclusion that plants and metals have life on the basis of the electric nature of living things. When a part of the body feels pain, nerves carry electric signals from it to the brain for information. Similarly, when a hand is to be moved, the brain communicates the order to do so by an electric signal. So also the brain, muscles and heart in an animal function on electric signals. Bose showed experimentally that, though plants do not have a brain, muscle or heart, there are small cells in them which behave in the same manner. The only difference between the response of a plant and of an animal is of time. A plant takes a longer time to respond.

Although Bose did most of his experiments in Calcutta, not many of his countrymen recognised their importance. Notable exceptions were Mahatma Gandhi, Rabindranath Tagore and Swami Vivekananda.

His work was applauded in the country only when the Western world recognised its importance.

Before Bose died on November 23, 1937, he founded the Bose Institute at Calcutta. It was then devoted mainly to the study of plants. Today, research on several other related subjects is also in progress at the institute.

Birbal Sahni

In 1932, a foreign scientist who came to Lucknow University to meet Birbal Sahni, the greatest palaeobotanist India has ever produced, was amazed to find the professor sitting in a corner of the small botany museum.

"Hello, Professor Sahni!" he said, shaking hands, "you don't even have a room to yourself!"

"Great scientists have worked in garrets," replied Sahni with a smile.

Palaeobotany, the study of plants of past ages, was then a new science in the country. No equipment was available to cut and grind rocks so that the fossils of extinct plants that they carry could be studied. Sahni spent much of his time doing this work with his own skilled hands. He even used to spend his own money to buy tools. In fact, to build an institute wholly devoted to palaeobotanical studies was his ambition.

Being a teacher, Sahni first raised the standard of teaching at the Department of Botany. Next he established the Department of Geology. A logical sequence was the establishment of the institute of palaeobotany. It was the first of its kind in the world. A week after Jawaharlal Nehru laid the foundation stone of the building in 1949, Sahni died. His wife completed the task he had left undone. The institute is today known as the Birbal Sahni Institute of Palaeobotany.

Sahni was born on November 14, 1891, at Bhera (Punjab) now in Pakistan. His father was a chemistry teacher who was interested in the study of nature. During vacations the older Sahni used to take the boy on treks in the mountains. Together they used to collect rocks, plants and fossil-bearing rocks. The young Sahni became so interested in botany and geology that, against the wishes of his father, who was keen that he join the Indian Civil Service, he took them up as his career.

After graduating from Punjab University, Lahore, in 1911, Sahni went to Britain. In 1919 he secured his D.Sc. from London University. Subsequently, he took up research on ferns, conifers and fossil plants under the guidance of a noted botanist, A.C. Steward. In 1929 he became the first Indian to get a D.Sc. from Cambridge University, a rare distinction then. In 1936 he was elected Fellow of the Royal Society.

Palaeobotany is a subject which needs knowledge of both botany and geology. It also calls for an adventurous spirit and a physique good enough for trekking on the mountains in search of rocks that contain plant fossils. Once the rocks have been collected and ground, the abilities of a detective are required to piece together the picture of that ancient plant from the scattered information available in the fossils. From childhood Sahni had acquired these qualities.

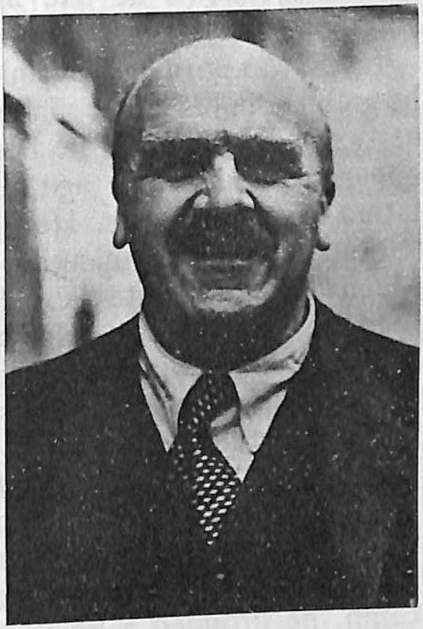
He was the first botanist to study extensively the flora of Indian Gondwana. He also explored the Raj Mahal hills in Bihar, which is a treasury of fossils of ancient plants. Here he discovered some new genus of plants. The important and interesting ones are *Homoxylon rajamahalense*, *Rajamahalia paradora* and *Williamsonia sewardiana*. Some of his discoveries have helped in understanding the evolutionary relationship between certain species of plants of the present and past ages.

He also discovered a new group of fossil gymnosperms (conifers and their allies) called "*pentoxyleae*," which attracted world-wide attention. Some of his palaeobotanical studies have even given support to the continental drift theory. According to this theory continents have always been drifting on the surface of the earth, just as a raft does on the surface currents of a river.

Sahni was a geologist too. Using crude instruments and his vast knowledge of ancient plants, he estimated the age of some old rocks. He showed that the age of the Salt Range, now in Pakistan Punjab, is 40 to 60 million years old and not about 100 million years, as believed till then. He found that the Deccan Traps in Madhya Pradesh were of the tertiary period, about 62 million years old.

Besides, Sahni took a keen interst in archaeology. One of his investigations led to the discovery of coin moulds in Rohtak in 1936. For his studies on the technique of casting coins in ancient India he was awarded the Nelson Wright Medal of the Numismatic Society of India.

He was also good at painting and clay modelling and had a large collection of stamps and coins.



J. B. S. Haldane

A two-year-old boy was making curious faces at the mirror before him. His mother asked him what he was up to. "Trying to copy dogs, Mummy," replied the boy. There are various types of dogs, some with long noses, some with square faces and some with funny eyes. This boy was experimenting to find out how best to look like the dogs he had seen near his house. This quality of experimenting upon himself was to remain with John Burdon Sanderson Haldane, the English-born Indian biologist, throughout his life. He used to conduct horrifying experiments upon his own body to test how it behaved under different conditions.

Sometimes, after an experiment on himself, J.B.S., as he was popularly known, used to lie panting in bed for weeks together. But such was his dedication to science that whether he was feeling pain or was about to vomit he used to go on recording whatever was happening to him. The savage courage required for such experiments he had inherited from his father, John Scott Haldane, a noted physiologist.

J.B.S. was born on November 5, 1892, at Oxford and he grew up in his father's laboratory in the house. Very early in his childhood he began to toy with scientific apparatus and by the age of eight began to help his father in experiments. He also accompanied him on various hazardous scientific trips into deep mines. Meanwhile he learnt several languages and on his own read diverse subjects. His brilliance in mathematics enabled him to win the Russell Prize at the age of 16.

The training in fearlessness J.B.S. received from his father made him a "different" boy. During World War I he was popular among his troops as "Rombo". It is said that he used to sneak into enemy lines at night and return with valuable information. Once, when he heard something nasty being talked about Britain in an enemy camp, he dropped a bomb there in anger and came back under heavy fire.

J.B.S. was a hefty man with a short temper and a booming voice, but at heart he was sentimental and sympathetic.

He had his basic education in humanities, but he took up scientific research as a career. Under the guidance of his father he first did research in physiology, the study of the processes happening inside a living body, at Oxford. In 1922 he joined Cambridge University and did research in biochemistry, the study of chemical reactions taking place inside a living body, under the discoverer of vitamins, Frederick Gowland

Hopkins. In 1925 he became interested in genetics, the study of heredity and variation, and his brilliant work led to his being elected Fellow of the Royal Society in 1932. A year later he joined University College, London, as Professor of Genetics, a position he held as long as he stayed in Britain.

J.B.S. made original contributions to several diverse subjects — physiology, medicine, evolution, genetics, biochemistry, mathematics, cosmology. Renowned for his experiments on himself, he was also excellent at mathematics and utilised it fully in his biological researches. He believed that "if you are faced with a difficulty or a controversy in science, an ounce of algebra is worth a ton of verbal argument".

In fact, he was the first to use mathematics in genetics. Among his significant contributions is an estimate of the rate of mutation of a human gene. Mutation is a sudden change in a gene which enables a child to inherit a characteristic totally absent in his or her parents. He calculated that mutation occurs once for every 50,000 people per generation. Through such calculations he was able to show that Darwin's theory of evolution is correct. Using the latest findings in biochemistry he also explained how life could have originated on the earth from a "hot dilute soup" of certain chemicals.

Some of his discoveries in biochemistry have already become laws of enzyme chemistry. Enzyme is an organic catalyst which assists in speeding up some chemical processes occurring inside a living body. His findings in physiology are also noteworthy. Through experimentation upon himself he studied how chemicals, carbon dioxide gas, ice cold temperature and the like affect breath. From these studies he also discovered a cure for tetanus and convulsions.

J.B.S. was not a scientist confined to the laboratory. He was also a social worker who fought for causes. From his boyhood days when he used to meet miners and fishermen, he had attained respect for the common man. During World War II he criticised the air raid precautions taken by the British Government, calling them inadequate.

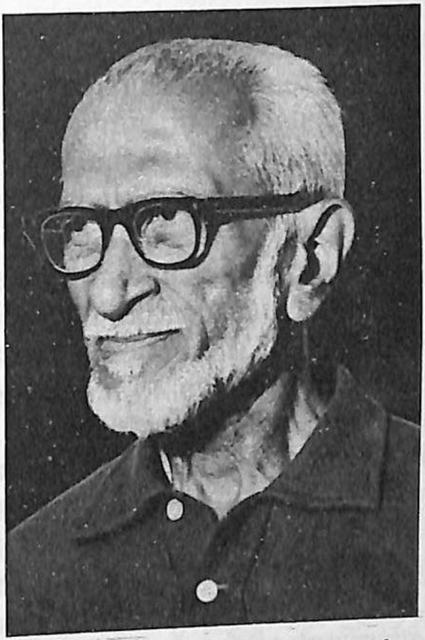
To tell laymen what science is and what it stands for, J.B.S. also wrote popular science articles and gave lectures. He wrote on varied subjects from genetics to politics. Some of his most famous books are: *The Causes of Evolution, What is life?* and *Science and Ethics*. He also wrote *My friend, Mr Leakey* for the benefit of children. In science popularisation his writings are at par with those of Julian Huxley, an eminent biologist. Some of the ideas he discussed in his writings and lectures made a profound impact on research.

He left the United Kingdom in 1957 and came to live in India, a country he had come to love during several visits. He was inspired by Hindu philosophy, the Hindu way of life and the principle of non-violence. The *Gita* impressed him. He even liked the *dhoti* and *kurta* and used to wear them.

J.B.S. came to India with a purpose. He knew the country contained a large variety of animals and plants in large number. He, therefore, wanted to develop research in biology. He gave science lectures at various places and also guided young scientists in their research. He was first appointed a professor at the Indian Statistical Institute, Calcutta, and later became Director, Genetics and Biometry Laboratory, in Bhubaneshwar, Orissa.

At the age of 71 he died of cancer at Bhubaneswar. Even during his illness, he wrote a cheerful poem, *Cancer's a Funny Thing*, which is considered to be one of the best poems written on a scientific subject.

Salim Ali



Bang! A bird fluttered for seconds and fell to the ground. A ten-year old bespectacled boy, who had shot the bird, ran and picked it up. The bird looked like a house sparrow but, to the boy's surprise, it had a yellow patch on its throat. Puzzled, the boy took the sparrow to his uncle, Amiruddin Tyabji, a big game hunter, and asked him what kind of bird it was. His uncle did not know, but took the boy to the office of the Bombay Natural History Society, a tiny room in a huge building in Apollo Street. The boy was introduced to W. S. Millard, the honorary secretary of the society.

Millard was amused to find an Indian boy keen to know the kind of sparrow he had bagged. He took him around the room, showing the many varieties of stuffed birds preserved there. One after another, drawers were opened and birds were displayed to the boy, who had not even imagined that so many kinds of them existed.

He gasped when Millard opened a drawer which contained a large variety of sparrows. Examining carefully, Millard picked up one and showed it to the boy. Sure enough, the bird was exactly like the one he had brought with him — a yellow throated sparrow.

"Uncle Millard," the boy exclaimed, "I didn't know there were so many kinds of birds! I wish to learn about them all!"

Millard smiled and nodded. He had till then not seen so much enthusiasm about birds even in an adult. Thereafter, the boy became a frequent visitor to that office. He began to learn how to identify a bird and stuff it for preservation.

The boy was Salim Moizuddin Abdul Ali, better known as Salim Ali, bird watcher extraordinary. Born on November 12, 1896, Salim Ali, now in his late eighties, is even today as interested in birds as he was when he was first introduced to Millard. He is a recipient of the J. Paul Getty Wild Life Conservation Prize for his contributions to ornithology, the study of birds. He has won several national honours and awards as well.

Surprisingly, Salim Ali has no university degree. Although he joined college, his intense dislike of algebra and logarithm did not allow him to continue his studies. He left for Burma to help his brother in wolfram mining. But here again he proved a failure. In the jungles of Burma he looked for birds instead of wolfram.

When he returned home he did a course in zoology and was appointed a guide at the museum of the Bombay Natural History Society. For some advanced training in stuffing and skinning of birds he went to Germany. But when he returned a year later, he found himself on the streets. For lack of funds his post in the museum had been abolished in his absence.

Salim Ali was a married man and badly needed a job. But the best he could hope for was a clerk's post and that would leave him little time to pursue his interest in birds. Luckily, his wife had a small income and could support him. They moved to a small house at Kihim, across the harbour.

It was a quiet place set in the midst of trees. When the monsoon came that year, Salim Ali found a colony of weaver birds on a tree near his house. Not much was known about weaver birds then and it was a golden opportunity for Salim Ali to study them. For three or four months he patiently watched the activities in the colony for hours on end. The publication of his findings in 1930 brought him recognition in the field of ornithology and he won high acclaim.

The months he had spent watching the weaver birds also taught Salim Ali the importance of making first-hand observations and not to accept blindly the notions of any one, however famous. He checks his observations several times and does not jump to conclusions. This has given his opinions great authority and sometimes brought him into confrontation with others considered to be doyens among ornithologists.

A famous instance was his observations on the growth of the tail feathers of the racket-tailed drongo. A leading ornithologist claimed that Salim Ali's observations were wrong. But, eventually, Salim Ali was proved right. His discovery of Finn's Baya is also a major one. This bird was believed to have been extinct for 100 years until he discovered it in the Kumaon hills.

As a boy Salim Ali had felt the need for a good book on Indian birds. The few books then available were without illustrations and contained long, dull descriptions, which were more likely to kill than kindle interest in birds, especially among young readers. In 1941 he tried to remedy this. *The Book of Indian Birds* that he wrote contained lively descriptions and coloured pictures of every species. It made spotting a bird easy for the layman.

In 1948 he began an ambitious project in collaboration with S. Dillon Ripley, an ornithologist of international repute, to bring out in ten volumes *Handbook of the Birds of India and Pakistan*. The work contains all that is known of birds of the subcontinent, their appearance, where they are generally found, their breeding habits, migration and what remains to be studied about them.

Salim Ali has travelled all over the country on his bird-watching surveys. It is claimed that there is hardly a place in the country where his heavy rubber shoes have not left their mark.

Weaver birds

According to the observations of Salim Ali, in a weaver bird colony the chief architects and craftsmen are always the males. Using paddy leaves and coarse grass they choose the site and start weaving their bottle-shaped nests. When the nests are almost ready, the females arrive and each chooses one nest after due inspection.

The female bird helps in giving the finishing touches to the nest and then lays eggs. As it sits brooding over them, the male leaves her and starts weaving another nest. When it nears completion, another female arrives and the two live together till the female begins brooding over the eggs. The male may then again leave her and start weaving another nest.

Thus a male weaver bird has two or more families at the same time. It, however, wisely restricts itself to weaving the nests. The job of feeding the brood is left to the females.

P. Maheshwari

In the heyday of science at Allahabad University students from all parts of the country used to flock to it. Of the hundreds who entered it in July, 1921, was Panchanan Maheshwari. At the Ewing Christian College, where he was admitted to the B.Sc. course was Winfield Dudgeon, an American missionary, who was a renowned botanist and founder-President of the Indian Botanical Society. Although students revered him, he was also feared as a taskmaster hard to please. But in Maheshwari Dudgeon found a student he had long been looking for.

Dudgeon used to take Maheshwari on expeditions to collect botanical specimens and taught him the basic techniques in plant morphology. On one occasion Dudgeon told Maheshwari, "a Hindu father believes his life's aim is fulfilled if he has given his son a good education. My son is dead, but I wish to leave behind at least one student who will carry on my mission."

After doing his M.Sc. Maheshwari took up research under Dudgeon's guidance. He studied the morphology, anatomy and embryology of some angiosperms, the class of plants which produce flowers.

We know that ovules in the flower of a plant fertilizes when an insect or wind brings to it pollen from another plant. This occurs in a cavity inside the flower called "ovary" and an embryo is the result . The embryo, the unborn baby plant, gets nutrition and food from the surrounding soil to grow up and become a plant. The way the embryo grows up to become a full-fledged plant differs from species to species. Maheshwari studied this process of growth in several species of angiosperms. He also classified them according to the differences he found in such embryological studies.

In 1931 Maheshwari secured his D.Sc. Before leaving Allahabad University, he went to Dudgeon to pay his regards. He told him, "Sir, you have done so much for me. What can I do for you in return?" Pat came the reply, "Do for your students what I have done for you." This message the young man took to heart. Wherever he went thereafter, whether it was Agra, Dacca or Delhi, he tried to do that. He also worked tirelessly. In addition to winning the Birbal Sahni Medal and the Sunder Lal Hora Memorial Medal, he was elected Fellow of the Royal Society in 1965.

Maheshwari was born on November 9, 1904, in Jaipur, Rajasthan. His father, though a clerk, was keen that his son should receive the best possible education. Not only did he train him to spend life in a disciplined manner, but worked long hours to raise the money needed for his son's education. He used to buy a lot of books for young Maheshwari. In fact, Maheshwari himself spent more than he could afford on books and laboratory material. He always had a small laboratory at home and did research there in his spare hours.

In 1949 Maheshwari was invited to head the new Department of Botany at Delhi University. He came determined to get his students interested in plant embryology, his own specialised field, which was neglected almost everywhere. He decided to carry out research in this field using not very expensive equipment. His efforts were crowned with success. Not only did the department develop and gain recognition abroad, but scientists elsewhere began to take up research in this field. Maheshwari can well be called the father of modern embryology.

It was he who invented the technique of test-tube fertilization of angiosperms. Till then no one thought that flowering plants could be fertilized in test-tubes. Maheshwari's technique immediately opened up new avenues in plant embryology and has applications in economic and applied botany. Cross-breeding of many flowering plants which cannot crossbreed naturally can be done now. The technique is proving to be of immense help to plant breeders.

In class Maheshwari was like his *guru,* Dudgeon. His students both loved and feared him. In his honour they named many newly discovered species of plants, like *Panchanania Jaipuriensis* and *Isoetes Panchananii.* Though renowned as an embryologist, he was well versed in other botanical fields. Maheshwari wrote two authoritative books, *An Introduction to the Embryology of Angiosperms* and *Recent Advances in Embryology of Angiosperms.* He also wrote books for schools to improve the standard of teaching life sciences. In 1951 he founded the International Society of Plant Morphologists. Till his death on May 18, 1966, he was editing its journal *Phytomorphology.*

Test-tube fertilization

A specially prepared nutrient medium is taken and solidified in a test-tube. Under aseptic conditions some ovules and "fresh" pollen grains are sprinkled on the medium. In due course, the pollen grains germinate and pollen tubes begin to grow towards the developed ovules. Within a few days fertilization is achieved with the pollen tube releasing sperms into the embryo sacs of the ovules. The product is the seed of the plant.

In the test-tube, fertilization takes place quicker than it does in nature. The so-called period of dormancy of seed is eliminated here. The development of embryo and endosperm takes place as in nature.

B. P. Pal

At an early age Benjamin Peary Pal was introduced to plants. His father, though a physician, used to spend his spare time growing flowers and vegetables in their garden. Once when he was tired he asked teenaged Pal to look after the garden. Pal not only began to take care of the plants but also started improving it after reading books on gardening and seed catalogues. Plants became his lifelong friends. Even today, in his seventies, he takes care of them with as much affection as he did when he was a boy.

Pal was born at Mukundpur, Punjab, on May 26, 1906. He spent his early life in Burma, where during his school and college days he won many prizes and scholarships. In 1929 he went to Cambridge to do research on wheat and he returned to Burma with a Ph.D. five years later. In 1933 he got a research job with what is now known as the Indian Agricultural Research Institute in New Delhi.

In pre-independence days not much agricultural research was in progress in the country. Disease used to destroy a major portion of the crops. Wheat was particularly susceptible to rust, a kind of fungal disease which damages a plant just as rust corrodes iron. Although some varieties of wheat that could give higher yields had been found, there was none that could combat rust. Pal decided to develop new varieties of wheat which could do so.

He developed NP (New Pusa) 700 and NP 800 series, which could combat a particular type of rust. But the real breakthrough came only in 1954 when he developed the NP 809 after 18 years of painstaking research. This variety of wheat can combat all three types of rust and it was a big step forward in increasing wheat production. He was applauded the world over for this remarkable achievement.

In 1965 Pal became Director General of the newly founded Indian Council of Agricultural Research in New Delhi. Because of his efforts the Council is today playing a key role in the country's agricultural progress. The origin of the Green Revolution can be traced to his researches and plans. For his significant contribution to science, he was awarded the Rafi Ahmed Kidwai Prize, the Birbal Sahni Medal and the S. Ramanujan Medal. He also won other State honours and in 1972 was elected Fellow of the Royal Society.

Pal has also done significant research on roses and developed more than forty varieties of them. He has written several books on roses, the most popular being *The Rose in India.*

M. S. Swaminathan

Till the late fifties food production in the country was insufficient to meet its requirements. There was no solution in sight and even the future appeared bleak.

For Monkombu Sambasivan Swaminathan, a young scientist at the Indian Agricultural Research Institute, this was a challenge. After persistent research he felt that Nobel Laureate N.E. Borlaug's newly developed Mexican dwarf wheat variety could solve the wheat problem.

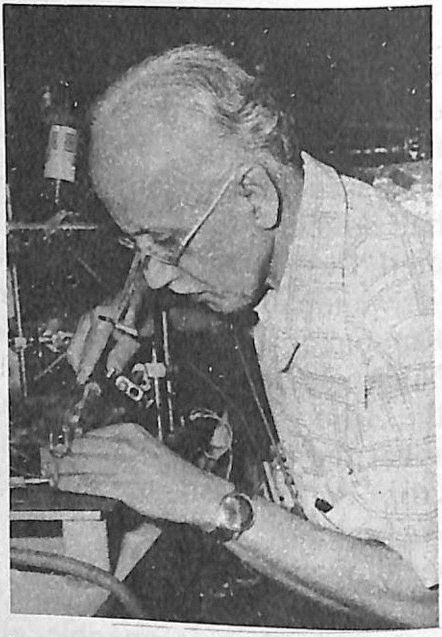
On Swaminathan's initiative Borlaug visited India to study the situation and he provided a range of Mexican dwarf wheat varieties. They were found to be suitable for cultivation in this country and wheat production increased dramatically. Within a decade production had doubled. Like Pal before him Swaminathan is one of those responsible for the Green Revolution.

Swaminathan was born on August 7, 1925, at Kumbakonam and had his basic education in Tamil Nadu. He then went to Britain and took his Ph.D. from the School of Agriculture in Cambridge in 1952. He spent the next two decades doing research on various crops and in basic and applied genetics at the Indian Agricultural Research Institute. He developed high yielding strains of wheat and rice and accomplished difficult crosses in potato and jute species.

Swaminathan is an able administrator and social worker, a rare quality in a scientist. He has been formulating various schemes and projects to provide the benefits of research done in the laboratory to the farmer in the field. He has also introduced modern methods and techniques to raise agricultural production. In 1971 he was awarded the Ramon Magsaysay Award for generating a new confidence in the agricultural capabilities of the country. In 1973 he was elected Fellow of the Royal Society. He has also received the S.S. Bhatnagar Award, the Birbal Sahni Medal and the Mendel Memorial Award.

At present he is Director of the International Rice Research Institute, Phillipines.

A. S. Paintal



When people, whether young or old, climb a mountain, they are easily tired. If they still over exert themselves, breathlessness overcomes them and they must rest. It has been found that, if people ignore these warnings, they sometimes die of congestion of the lungs, called pulmonary congestion.

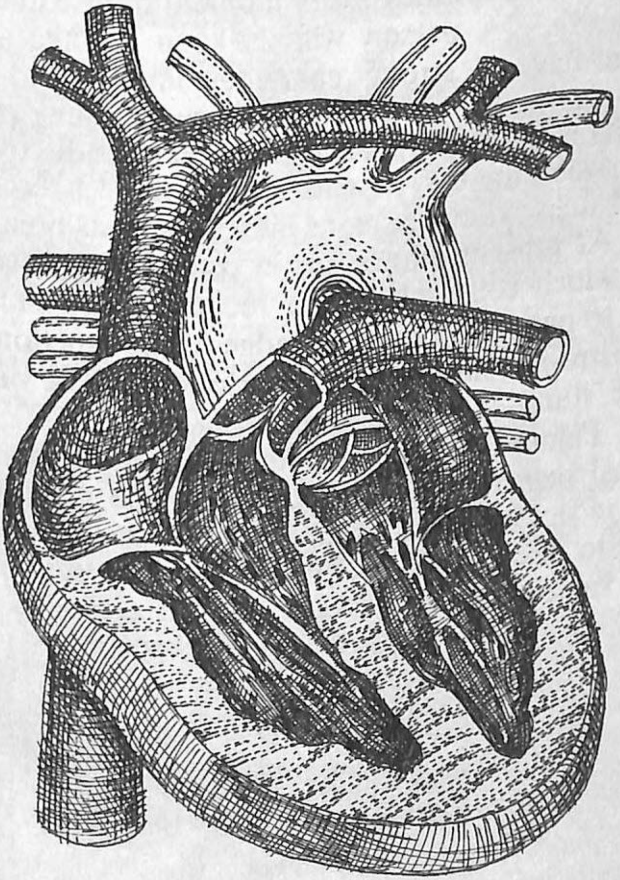
What is it that warns an overenthusiastic climber? It is the nerve terminals in the lungs called "juxtapulmonary capillery receptors" or simply "J-receptors".

Likewise, what is it that warns you that your stomach is full and cannot take any more food or water? It is, again the nerve terminals in the stomach, "gastrointestinal stretch receptors."

Do you know who discovered these receptors in the human body? He is Dr. Avtar Singh Paintal, now Director of the Vallabhbhai Patel Chest Institute in Delhi. In 1981 he became the first Indian medical scientist to be elected Fellow of the Royal Society.

Paintal was born at Mogok, Burma, a place renowned in the old days for its rubies. His father was a doctor. Young Paintal had, therefore, the opportunity of seeing his father perform operations. He thus became interested in biology. Popular science books further stimulated his interest in science. In fact, he used to pester his parents for money to buy books.

Eventually, he secured admission to Lucknow Medical College and had a brilliant academic career. He, however, says now, "I wasted a lot of time trying to come first, while I should have been reading magazines like *Scientific American* which contain solid science."



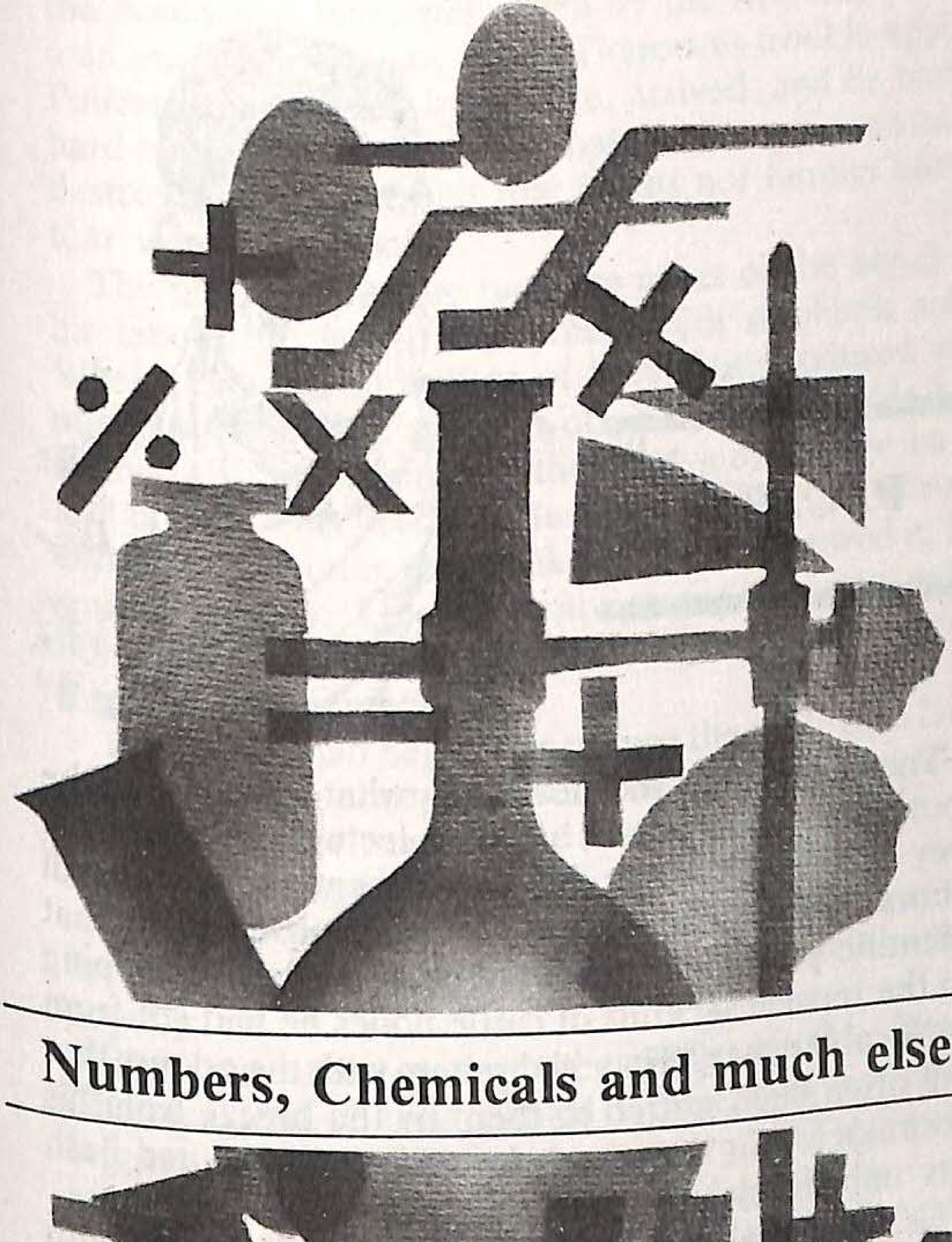
In 1950, on a Rockefeller fellowship, he went to Edinburgh in Britain to do his Ph.D. under Professor D. Whitteridge, an eminent medical scientist.

At Edinburgh Dr. Paintal conducted a marvellous experiment which surprised even Professor Whitteridge. He discovered a pair of "volume receptors" in the heart, whereas his guide had expected them in the lungs. These receptors control the volume of fluid in the body.

After taking his Ph.D. he returned to India and in 1954 joined the Patel Chest Institute as Assistant Director, where he has been since. Among other things, he discovered the "J-receptors" in 1955. Dr. Paintal seems to enjoy every moment of research in his laboratory. "A person who is keen to take science should have a strong character and should avoid short-cuts in general," is his advice to young people.

What is the importance of Dr. Paintal's discoveries? Understanding the functioning of the "J-receptors" would help relieve persons suffering from breathlessness. At present efforts are in progress to discover a drug which could block the receptors and thus give relief to patients. The knowledge of the functioning of the gastro-intestine stretch receptors would be valuable in the study of gastric ulcers.

Dr. Paintal has also introduced new techniques in medical research which have led to the discovery of other receptors in the lungs, heart and intestines. He is trying to develop a screening test to find out who are more susceptible to sickness at high altitudes.



Numbers, Chemicals and much else

P. C. Ray

The neighbours did not know what to make of the young man. That he was a college lecturer and scientist, they knew. And he did experiments in the small laboratory he had set up at his house. But what scientific purpose could he hope to serve by dumping on the terrace sackfuls of cattle bones he had got from the local butcher? They had put up with the odours that had often been wafted to them by the breeze from his laboratory. But the stench from rotting bone and flesh was unbearable.

Crows had also been littering houses all around with bones picked up from the terrace. After several days of this they could stand it no longer. They told the young man to take away the bones. If he did not, they would call the municipal authorities.

At this juncture a friend came to the rescue of the young man. He had a vacant plot of land a little away from houses and the bones could be dumped there. That was done, and one evening, when he found that the bones had been well dried by the sun, the young man made a bonfire of them. There was trouble again. Policemen, attracted by the fire, arrived, and he had a hard time convincing them that he was no murderer destroying evidence and that it was not human bones that were being burnt.

The next morning he took the ashes of the bones to his laboratory and treated them with sulphuric acid. When the superphosphate of lime thus produced was mixed with soda, a solution of phosphate of soda was formed. The solution was then put into a large basin and boiled. This produced lumps of phosphate of soda crystals. The young man took a lump and chewed it. He smiled happily. He had converted the waste cattle bones into a medicinal compound from which a nerve tonic could be made.

The young man began to produce the tonic on a large scale. It was cheaper than the imported product available in the market and was as effective. In the beginning, druggists were not ready to keep this *deshi* medicine, but doctors who knew the young man and the effectiveness of the tonic canvassed it and it became popular.

This was the modest beginning of the Bengal Chemical and Pharmaceutical Works, now one of the biggest chemical firms in the country, and the young man was Prafulla Chandra Ray. Today, Ray is recognised as the father of India's chemical industry. And he not only developed centres of research in chemistry and trained brilliant young chemists but also, by original research, placed India in a high position in the world of chemistry.

A hundred years ago India was altogether different from the country we know today. There was hardly any industry in the country. The British used to send raw materials from the land to Britain and elsewhere to feed their industries. The products they manufactured were imported to India to be sold at high prices. The result was costly imported products and widespread unemployment in the country.

In 1888, when Ray returned from Edinburgh with a D.Sc., the plight of the country disturbed him. He discarded European dress, began to wear *khaddar* and decided to do something to industrialise the country. Ray got the post of lecturer at Presidency College in Calcutta. He had only a small salary, but he saved what he could to provide the capital he required to start an industry.

In his spare time he conducted experiments in his laboratory at home. He first took to the production of citric acid from lemon and citron. It proved to be a failure, as lemon and citron were costly and citric acid was cheaply available in the market.

He had read in a textbook that "sulphuric acid is the mother of industries". Therefore, he tried to produce the acid. When he met with failure again, phosphate of soda attracted his attention. With his "cattle bones experiment" he eventually succeeded. The industry he set up prospered. What is more, his example was followed by others. Industries began to grow in the country. Before he died in 1944 all his dreams had come true, except the independence of the country, which came three years later.

Ray was born on August 2, 1861, at Raruli-Katipara, now in Bangladesh, in a wealthy and cultured family. His interest turned from literature to science after he read Benjamin Franklin's *Autobiography*. Franklin's famous "kite experiment" to know the nature of lightning thrilled him. Apart from proficiency in various languages, Sanskrit, Latin, French and English, he was well versed in politics, economics and history.

Ray did not marry and lived among his friends and students. Although the industry he had built was amassing lakhs of rupees, he lived like a hermit. He would not spend a *paisa* more than was necessary on himself, but would donate thousands of rupees for the benefit of the poor and the afflicted. He took an active part in politics. Mahatma Gandhi and G.K. Gokhle were among his friends.

His main contribution to chemistry was the discovery of mercurous nitrite in 1896. He also extracted several of its derivatives. His book, *The History of Hindu Chemistry,* has been widely acclaimed.

D. N. Wadia

There was nothing in the childhood of Darashaw Nosherwan Wadia to suggest that he would become a geologist. And a renowned one at that.

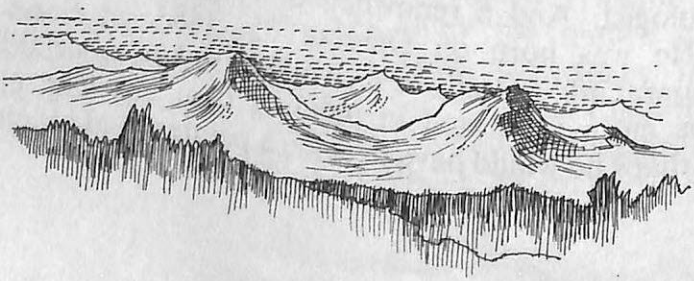
He was born on October 25, 1883, at Surat in Gujarat into a family of ship-builders. And as a child he was more interested in painting than anything else. Perhaps he would have become a painter, had his elder brother not lured him to science. At Baroda College, Wadia did his M.Sc. in biology and geology. At the age of 23 he joined the teaching staff of the Prince of Wales College in Jammu.

Living as he was at the foothills of the Himalayas, geology became his main interest. During vacations he would go to the Himalayas and collect minerals, rocks and fossils. Till his death in 1969, he continued to study the geology of the Himalayas.

Wadia is world renowned for his studies of the Himalayas. He not only gave the mechanism of their formation and growth, but tried to explain the various puzzling features in their structure—for example, the acute hairpin bend in the Eastern Himalayas. Besides, he studied the geology of Joya Mair dome (now in Pakistan), Nanga Parbat and Ceylon (now Sri Lanka). He was also an expert palaeontologist. Among his important discoveries of invertebrate fossils and plants is one of the skull fragments of *Stegodon Ganesa,* shaped like an elephant.

To interest students in geology, Wadia wrote *The Geology of India and Burma* in 1916. He always said that India had vast resources waiting to be tapped. He played a significant role in laying the foundation of geological studies in Sri Lanka.

For his contributions to geology Wadia received the Back Award, the Lyell Medal and the Meghnad Saha Medal. In 1957 he was elected Fellow of the Royal Society, the only Indian geologist so far to be given this honour.



S. Ramanujan

The arithmetic class was in progress. The teacher was solving questions on division. On the blackboard were drawn three bananas.

"We have three bananas," the teacher said, "and we have three boys. Can you tell me how many each will get?"

A smart boy in the front row replied, "Each will get one."

"Right," the teacher said. "Now, similarly, if 1,000 bananas are distributed among 1,000 boys, each will get one, isn't that so?"

While the teacher was explaining, a boy sitting in one corner raised his hand and stood up. The teacher stopped and waited for the boy to speak.

"Sir," the boy asked, "if no banana is distributed among no one, will everyone still get one banana?" There was a roar of laughter in the class. What a silly question to ask!

"Quiet," the teacher said loudly and thumped the desk. "There's nothing to laugh at. I will just explain what he means to say. For the division of bananas, we divided three by three, saying that each boy will get one banana. Similarly, we divided 1,000 by 1,000 to get one. What he is asking is that if zero banana is divided among zero, will each one get one? The answer is 'no'. Mathematically, each will get an infinite number of bananas!"

Everyone laughed again. The boys understood the trick arithmetic had played upon them. What they could not understand was why the teacher later complimented the boy who had asked that absurd question.

The boy had asked a question that had taken mathematicians several centuries to answer. Some mathematicians claimed that zero divided by zero was zero. Others claimed it to be unity. It was the Indian mathematician Bhaskara who proved that it is infinity. The boy who asked the intriguing question was Srinivasa Ramanujan. Throughout his life, whether in his native Kumbakonam or Cambridge, he was always ahead of his mathematics teachers.

Ramanujan was born at Erode in Tamil Nadu on December 22, 1887. His father was a petty clerk in a cloth shop. From early childhood it was evident that he was a prodigy. Senior students used to go to his dingy house to get their difficulties in mathematics solved. At the age of 13 Ramanujan was able to get Loney's *Trigonometry* from a college library. Not only did he master this rather difficult book but also began his own research. He came forth with many mathematical theorems and formulae not given in the book, though they had been discovered much earlier by great mathematicians.

The most significant turn came two years later when one of his senior friends showed him *Synopsis of Elementary Results in Pure and Applied Mathematics* by George Shoobridge Carr. For a boy of 15 the title itself must be frightening, but Ramanujan was delighted. He took the book home and began to work on the problems given in it. This book triggered the mathematical genius in him.

Mathematical ideas began to come in such a flood to his mind that he was not able to write all of them down. He used to do problems on loose sheets of paper or on a slate and to jot the results down in notebooks. Before he went abroad he had filled three notebooks, which later became famous as Ramanujan's *Frayed Notebooks*. Even today mathematicians are studying them to prove or disprove the results given in them.

Although Ramanujan secured a first class in mathematics in the matriculation examination and was awarded the Subramanyan Scholarship, he failed twice in his first year arts examination in college, as he neglected other subjects such as history, English and physiology. This disappointed his father. When he found the boy always scribbling numbers and not doing much else, he thought Ramanujan had gone mad. "To set him right", he forced his son to marry. The girl chosen was eight-year-old Janaki.

Ramanujan began to look for a job. He had to find money not only for bread but for paper as well to do his calculations. He needed about 2,000 sheets of paper every month. Ramanujan started using even scraps of paper he found lying in the streets. Sometimes he used a red pen to write over what was written in blue ink on the piece of paper he had picked up.

Unkempt and uncouth, he would visit offices, showing everyone his frayed notebooks and telling them that he knew mathematics and could do a clerical job. But no one could understand what was written in the notebooks and his applications for jobs were turned down.

Luckily for him, he at last found someone who was impressed by his notebooks. He was the Director of the Madras Port Trust, Francis Spring, and he gave Ramanujan a clerical job on a monthly salary of Rs. 25. Later some teachers and educationists interested in mathematics initiated a move to provide Ramanujan with a research fellowship. On May 1, 1913, the University of Madras granted him a fellowship of Rs. 75 a month, though he had no qualifying degree.

A few months earlier, Ramanujan had sent a letter to the great mathematician G.H. Hardy, of Cambridge University, in which he set out 120 theorems and formulae. Among them was what is known as the Reimann series, a topic in the definite integral of calculus. But Ramanujan was ignorant of the work of the German mathematician, George F. Riemann, who had earlier arrived at the series, a rare achievement. Also included was Ramanujan's conjecture about the kind of equations called "modular". Pierre Deligne subsequently proved this conjecture to be correct. He also gave a key formula in the hypergeometric series, which came to be named after him.

It did not take long for Hardy and his colleague, J.E. Littlewood, to realise that they had discovered a rare mathematical genius. They made arrangements for Ramanujan's passage and stay at Cambridge University. On March 17, 1914, he sailed for Britain.

Ramanujan found himself a stranger at Cambridge. The cold was hard to bear and, being a Brahmin and a vegetarian, he had to cook his own food. However, he continued his research in mathematics with determination. In the company of Hardy and Littlewood he could forget much of the hardship he had to endure.

In Ramanujan Hardy found an unsystematic mathematician, similar to one who knows the Pythagorus theorem but does not know what a congruent triangle means. Several discrepancies in his research could be attributed to his lack of formal education. Ramanujan played with numbers, as a child would with a toy. It was sheer genius that led him to mathematical "truths". The task of proving them, so important in science, he left to lesser mortals.

Ramanujan was elected Fellow of the Royal Society on February 28, 1918. He was the second Indian to receive this distinguished fellowship. In October that year he became the first Indian to be elected Fellow of Trinity College, Cambridge. His achievements at Cambridge include the Hardy-Ramanujan-Littlewood circle method in number theory, Roger-Ramanujan's identities in partition of integers, a long list of the highest composite numbers, besides work on the number theory and the algebra of inequalities. In algebra his work on continued fractions is considered to be equal in importance to that of great mathematicians like Leonard Eular and Jacobi.

While Ramanujan continued his research work, tuberculosis, then an incurable disease, was devouring him. Ramanujan was sent back to India and when he disembarked, his friends found him pale, exhausted and emaciated. To forget the agonising pain, he continued to play with numbers even on his deathbed. On April 26, 1920, he died at Chetpet in Madras.

Besides being a mathematician, Ramanujan was an astrologer of repute and a good speaker. He used to give lectures on subjects like "God, Zero and Infinity".

P. C. Mahalanobis

Most beds are of standard size. Especilly those put in dormitories. The result is that those who are very tall have to learn to sleep curled up or with their feet dangling over the edge. Usually, no one would think of blaming any person for their plight, but at Santiniketan, the university set up by Rabindranath Tagore, the students were sure who was responsible for some of them losing their sleep. It had to be Prasanta Chandra Mahalanobis, the man with an obsession for statistics. It was thought that he must have found the students' average height and ordered the beds according to that specification.

Wherever Mahalanobis went he roused such good-humoured speculation. At that time not many people in the world, let alone India, understood statistics and their significance. And Mahalanobis was considered a crank. But, as Mark Twain said, "A man with a new idea is a crank, until the idea succeeds".

Mahalanobis's idea did eventually succeed. He was the first Indian statistician to receive world recognition. In fact, the history of statistics in India is his personal history. However, it was almost by chance that Mahalanobis came to be a statistician. He was selecting books from the library of King's College in London, where he was a mathematics student, when his tutor, W.H. Macaulay, happened to come there and suggested that he might find the latest volume of *Biometrica and Biometric Tables* interesting. On reading it Mahalanobis was so thrilled that he brought several volume of the journal when he came to India for his vacation.

That was in 1915 and as World War I was then raging Mahalanobis decided not to return to London. He had done his B.Sc. and took up a lecturership in physics at the Presidency College in Calcutta. In his spare time he continued his studies in statistics. Many thought he was wasting his time, but Rabindranath Tagore, who had known him from childhood, Brajendra Nath Seal, Professor of Philosophy at Calcutta University, and Sir Nilratan Sircar, his maternal uncle, encouraged him. Seal took a personal interest in the statistical studies of Mahalanobis and predicted that one day statistics would become a basic scientific tool.

Statistics is a subject which deals with numbers, which may have a relationship with one another or change in different situations. Using various statistical methods, a conclusion or conclusions can be inferred from the numbers. When in 1917 Seal wanted to look into the examination system of Calcutta University, Mahalanobis was consulted. An examination system means a lot of question papers, questions, students, teachers. Mahalanobis handled these numbers skilfully and forwarded recommendations which brought changes in the system.

Success in this endeavour prompted him to try his hand at problems in subjects like anthropology, epidemiology, demography and meteorology, which again deal with a mass of numbers. For instance, temperature, pressure, humidity and so on at various sites within a region are first collected and then processed statistically to predict the weather over the region.

Impressed by his successes, various authorities began to consult Mahalanobis to tackle their problems. For instance, in 1922 engineers attributed a disastrous flood that hit North Bengal to a rise in the river beds and advised the government to raise the embankments of rivers to control floods. Mahalanobis was consulted. Using the figures of rainfall and floods for the past 50 years, he arrived at a different conclusion. He told the authorities that a better drainage system for a smoother flow of rivers was the only requirement. When his advice was followed, it proved effective. Statistics had shown its worth. He did a similar study of floods in Orissa. The Hirakud Hydroelectric Project is based on his statistical studies and so is the Damodar Valley multipurpose hydroelectric project.

After India gained independence, it had to start several schemes for progress. Here statistics had a role and Mahalanobis was asked to give his advice. In 1958 he started his national sample surveys. A sample survey means assessing a situation by studying a part of it which would represent the whole. Some of his proposals were included in the second Five Year Plan.

At last Mahalanobis's dream was fulfilled. Not only was statistics being taught as a special subject in some universities, but it was also helping in the progress of the country. Meanwhile, he had founded the Indian Statistical Research Institute in Calcutta. The institute, which today has branches all over the country and conducts national sample surveys, gained international recognition within a short time.

Mahalanobis's contributions to statistics are of great importance. A few have already been included in textbooks. The tools he invented, like the ones called "Mahalanobis distance" and "fractile graphical analysis" have wide applications. For his original work he was elected Fellow of the Royal Society in 1945. He died in 1972 at the age of 79.

S. S. Bhatnagar

A British company was drilling for oil near Rawalpindi, when it came across an unexpected problem. The region was marshy. The mud that was drilled out combined with salty water to become a hard, rocky mass. Further drilling became extremely difficult and so work came to a standstill. The company faced a crisis. It began to look for someone who could solve the problem.

Finally it was referred to Shanti Swarup Bhatnagar. His contributions to emulsions and colloids were well known. A liquid is called emulsion when it is composed of two inseparable liquids. Milk is, for example, an emulsion because it is composed of water, other substances dissolved in water and cream fat. Colloid, on the other hand, is the gluelike state of any salt in a liquid. So the mud problem was the favourite research ground for Bhatnagar and he rose to the occasion.

After studying the problem at the Punjab University laboratory in Lahore (now in Pakistan), he advised the company to add an Indian gum to the mud drilled out. The gum made the mud less viscous and so did not allow it to harden. This quick and simple solution surprised the company officials. The company was saved from a huge loss. For this eleventh hour rescue the company rewarded Bhatnagar with Rs. 1,50,000 to continue his research on petroleum.

But Bhatnagar declined to take the money. Instead, he suggested that the company give the amount to Punjab University so that it could start research on petroleum. A new department was thus raised.

When scientists all over the land came to know of this, Bhatnagar was applauded. Among the many who sent him congratulatory messages was Meghnad Saha. His letter said: "India does not lack in men earning millions, but, if a few of those millionaires were guided by the fine example set by a comparatively poor teacher like yourself, I think her scientific and moral progress would have been rapid. Nobody but a true researcher can feel how much of our energies in this country are being wasted for lack of funds." Bhatnagar turned out to be one of the builders of scientific institutions in India.

Bhatnagar did research to make wax odourless, refine kerosene to increase flame height and utilise petroleum waste in the oil industry. He gave a large part of the money he received from his patents to provide more research facilities in Punjab University. He believed that science and technology were not for making money or for personal gain.

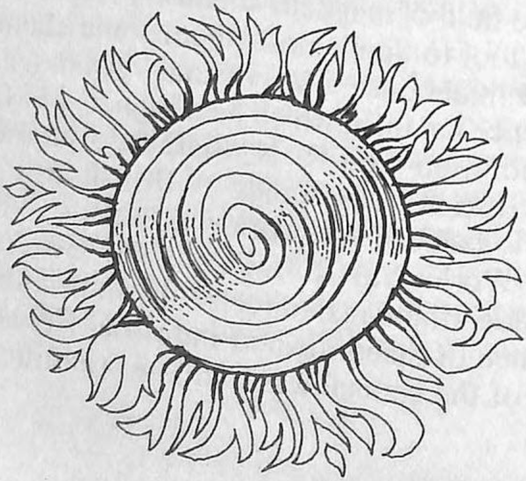
Bhatnagar was born on February 21, 1894, at Shahpur, now in Pakistan. His father died when he was only eight months old and he spent his childhood in the house of his maternal grandfather, an engineer. Naturally enough, he developed a liking for science and engineering. He used to enjoy building mechanical toys, electronic batteries, string telephones.

From his maternal family Bhatnagar also inherited the gift of poetry. In his college days he once wrote an Urdu one-act play, *Karamati,* and won the first prize in a competition. He in fact, excelled in many spheres, literary, scientific, dramatic and social. During his stay abroad he did excellent research on emulsions and received his D.Sc. from London University in 1921. Apart from his valuable work on emulsions, colloids and industrial chemistry, his fundamental contributions are in the field of magneto-chemistry. He used magnetism as a tool to know more about some chemicals and chemical reactions. The famous Bhatnagar-Mathur interference balance, which he designed and fabricated in collaboration with R. N. Mathur, a physicist, is of immense use in such studies. A British firm manufactured this balance for worldwide sale.

When World War II broke out, the Government of India made Bhatnagar director of what later became the Council of Scientific and Industrial Research. The purpose of the council was to utilise scientific research done in laboratories, in industries to produce better goods. Here was an opportunity for Bhatnagar to realize his dreams. For the war effort Bhatnagar produced in his laboratory such articles as anti-gas cloth, unburstable containers and plastics from waste.

He was elected Fellow of the Royal Society in 1943 for his scientific contributions. When the country gained independence, Bhatnagar began to lay the foundation for science and technology with the encouragement of Jawaharlal Nehru. Bhatnagar is responsible for installing oil refineries, plants to produce newer metals such as titanium and zirconium and planning surveys for atomic minerals and petroleum deposits.

Before he died on January 1, 1955, Bhatnagar had established twelve national laboratories which provide facilities for young scientists, who have just left the universities, to do research without having to go abroad. In his honour the Council of Scientific and Industrial Research awards every year the "Shanti Swarup Bhatnagar Prize for Science and Technology," a sum of Rs 20,000, to scientists for outstanding contributions to science, including engineering and technology.



T. R. Seshadri

In 1927 a young Indian started research under Robert Robinson, who later won the Nobel prize, at Manchester University. Within a few months he had his first test. He was asked to prepare in the laboratory some chemical compounds found in the rose and another flower.

Seeing that he was not familiar with such work, Robinson advised him to take up an easier project. But the young man said that he would not give up a project without giving it a fair trial. And to the surprise of everyone in the laboratory, he completed the project after a few months of hard work. He had passed Robinson's test and from that moment he never looked back.

The young man was Tiruvenkata Rajendra Seshadri, one of the founders of organic chemistry in India. Throughout his life he worked hard. A record number of 150 students did their Ph.D. under his guidance and he wrote 1,100 research papers. As a young man he first built the chemistry department of Andhra University, Waltair. Later he raised the chemistry department of Delhi University, to international level in the field of the chemistry of plant products. He was elected Fellow of the Royal Society in 1960.

Seshadri was born on February 3, 1900, in a poor but pious family at Kulittalai in Tamil Nadu. The religious atmosphere of places like Srirangam and Tiruchirapalli, where he spent his childhood, had an everlasting influence on him. And he never forgot that it was the Ramakrishna Mission that paid for his college education.

Under the guidance of good teachers at the Presidency College in Madras, his interest in chemistry bloomed. For his research there he was given several prizes and scholarships. In1927 he went to Manchester University for higher studies. When he returned, he would have secured a lucrative job anywhere. But he chose what was then a lowly paid career, that of researcher and teacher.

What makes a flower beautiful? Its colours, of course. But what chemical compounds in the plant make its flowers red or yellow? What chemical compounds make certain seeds and fruits astringent? What compounds does a teak tree produce which make its wood resistant to insects? What are the poisons and useful drugs found in certain plants? These are some of the questions that Seshadri investigated.

His research on hundreds of plants led to the discovery of many new chemical compounds. He studied their chemical structure and tried to produce them in the laboratory. He also tried to relate their chemical composition to their botanical classification.

Seshadri was considered an expert in the chemistry of lichens, a fungus-like growth. He not only discovered new compounds in them, but also studied how they damage sandal trees and archaeological monuments and ways to prevent such damage. Some of his findings are of great importance to agriculture and medicine.

Seshadri had great faith in God. He felt that science, philosophy and religion, if properly understood, were one and the same. He founded the Vedanta Samiti of Delhi University and used to take part in cultural and spiritual discussions. He died in 1975.

D. R. Kaprekar

Mathematics can be a fascinating game. Of course, few ever learn enough to play it. But Dattaraya Ramchandra Kaprekar became a player even as a child. If, while playing, he also made some significant discoveries, they were incidental. One of them, for which he is best known outside India is the "Kaprekar constant".

Kaprekar was born on January 17, 1905, at Dahanu, near Bombay. His mother died when he was barely eight years old. His father, who was a clerk, brought him up as best as he could. The clerk might not have known much of mathematics, but astrology was his hobby and he taught the child that.

Astrology introduced Kaprekar to the world of numbers. Calculations thrilled him. He started trying to find the shortest possible routes to solve mathematical problems. He used to spend hours solving mathematical puzzles and problems. In 1927 he won the Wrangler R. P. Paranjpe Mathematical Prize for an original piece of work in mathematics. In 1929 he took his B.Sc. from the Ferguson College in Pune and became a school teacher.

What is the "Kaprekar constant" that he discovered in 1946? It is the number 6174. To see how it is constant, take any four digit number in which not all digits are alike. Arrange the digits in descending order and reverse them to make a new number. Subtract the new number from the first number. If this process is repeated with the remainders, eventually, say, in eight steps or more, the constant 6174 is arrived at and this number then generates itself.

The procedure may seem easy now, but it took Kaprekar three years of labour and patience to arrive at the constant. He began calculations from a lower number and went on till he found the constant.

One set of numbers called "self numbers" is also known by his name. These are, so to say, self-born numbers. Kaprekar is also recognised for his significant contributions to Demlo numbers and other recreational mathematics problems. He has written books on his discoveries.

C. R. Rao

In 1941 a bespectacled young man came to Calcutta to secure a job. He had a first class first in M.A. mathematics from Andhra University. As he could find no place offering him research facilities, he was ready to take up any career. By chance he met a student of the Indian Statistical Institute. Curiosity made him accept an invitation to visit the institute, which he had not even heard of. What the young man saw in the three rooms of the Presidency College, to which the institute was then confined, fascinated him.

The rattling calculating machines, the colourful charts and sheets full of data were exciting. He immediately persuaded his father to allow him to join the institute for the M.A. course in statistics. He passed the course with honours, winning a gold medal.

The young man was Calyampudi Radhakrishna Rao, who came to be a renowned statistician. He was born on September 10, 1920, at Hadagali in Karnataka. His parents named him Radhakrishna because, like Lord

Krishna, he was their eighth male child. He had his schooling at several towns in Andhra Pradesh. For college education he went to Vishakapatnam. In his school and college he won several prizes and scholarships. Although he was greatly interested in physics, his father convinced him to take up mathematics, which, he said, was in the Indian tradition.

Rao first caught the attention of the world of statistics when in 1945 he put forward the "theory of estimation". The theory enables one to find an unknown quantity from a pile of data. In due course, he developed several statistical tools. His formulae and theorems, for instance the "Cramer-Rao inequality", "the Fisher-Rao theorem" and "Rao-Blackwellisation" are now part of any standard text on statistics.

Rao considers statistics to be a "very human science". What looks like a collection of numbers has indeed an immense significance in daily affairs. For example, his own technique of orthogonal (rightangular) arrays in the "design of experiments" assists industry in increasing production to the maximum. His contributions to multivariate analysis can be used in medical diagnosis, plant breeding and biometry. Biometry is the mathematical study of measurements in biology such as height, skull size, size of tail and geometry of flowers.

Earlier, in 1948, while doing his Ph.D. at Cambridge, Rao applied statistical methods to anthropology. He measured old skeletons of an African race to trace its origin statistically. In 1965 he worked in collaboration with Ronald A. Fisher, the celebrated statistician, on a genetics problem. Using statistics he mapped chromosomes in mice.

For his significant contributions Rao received the S. S. Bhatnagar Award, the Meghnad Saha Medal and the Guy medal. In 1967 he was elected Fellow of the Royal Society.

Rao has written more than half a dozen books on statistics. His *Linear Statistical Inference and Its Applications* has been translated into several languages. He is at present editor of *Sankhya,* the Indian statistical journal.

G. N. Ramachandran

When in 1952 the University of Madras made Gopalasamudram Narayana Ramachandran head of a department, though he was only 30 years old, no one was surprised. He had studied under two giants of science, C. V. Raman and Lawrence Bragg of Cambridge.

Ramachandran not only ran the department well but also introduced a new subject, molecular biophysics, concerning the giant molecules of a living body. Every chemical is made up of molecules. And scientists are even now trying to find the arrangement of molecules of certain chemicals produced in the human body, for example, proteins. Nobel Laureate Linus Pauling had then put forward a hypothesis about how molecules are arranged in some proteins and this fascinated Ramachandran. He, therefore, decided to take up research in this field.

At the suggestion of J. D. Bernal, the English historian of science and crystallographer, who was then on a visit to India, Ramachandran began research on the unclear molecular structure of collagen. Collagen is a commonly occuring protein in the human body and is found in connective tissues of the skin, bones and tendons as well as linings of many organs. Leather, for instance, is entirely collagen.

Through persistent efforts Ramachandran and his students finally established the way molecules are arranged in collagen. It has a triple helical structure. Today he is recognised the worldover for this significant discovery. He was awarded the Meghnad Saha Medal, the S. S. Bhatnagar Award and the Watumull Memorial Prize. In 1977 he was elected Fellow of the Royal Society.

Ramachandran later set up the molecular biophysics unit at the Indian Institute of Science in Bangalore and raised its status to an international level. Besides collagen, he and his students have studied other giant molecules of biological importance, for example, protein, nucleic acids and polysaccharides. He has also done research in varied fields, from crystals to meteorology to computer science.

"Be free, be strong and be original", is Ramachandran's advice to students. "Do not think that you should be wrong just because so many others say so. Accept that you are wrong only if your mind says so".

Devendra Lal

At 6.00 p.m. G.M.T. on November 22, 1973, an American astronaut, Edward Gibson, came out of Skylab-3 carrying a small packet. Crawling on the hull of the spacecraft on his life line he reached a pre-determined spot on the spacecraft and clamped the packet to it. More than two months later, on February 3, 1974, at the same hour, he came out again to retrieve the packet. This was not a space exercise but a vital scientific experiment which Devendra Lal and his colleague, S. Biswas, had proposed to the US National Aeronautical and Space Administration. The packet was a cosmic ray detector. To measure the intensity of cosmic rays in space was the purpose of the experiment.

When cosmic rays which come from space strike the surface of the earth, the ocean bed, the moon or a meteorite, they produce some nuclear changes and leave fine tracks in the rocks they traverse. Using a variety of techniques these "signatures" can be detected. As cosmic rays were present when the solar system was forming, their "signatures", millions of years old, in the rocks could be used to shed light on that period.

Lal made extensive studies of meteorites, of lunar rocks brought by the Apollo and Luna Missions and of material from the ocean bed. He also evolved techniques to understand past events in the solar system from cosmic ray "signatures." One of his most significant findings is that the intensity of cosmic rays during the last few million years has been the same as it is today.

Lal, one of the world's leading geophysicists, is associated with the Physical Research Laboratory, Ahmedabad. He is also visiting Professor of the Scripps Institution of Oceanography in California, USA

Lal was born on February 14, 1929, in Varanasi. During his school and college days he used to earn pocket money by selling cosmetics and varieties of ink he made at home. He joined the Tata Institute of Fundamental Research when he was only 20. Under the guidance of Prof. Bernard Peters, an eminent physicist, Lal learned the mysteries of research. No wonder he once remarked that "a good scientist should choose a good professor and learn from him the basic methods of science. Sitting at his feet is not sufficient, probably not even necessary".

For his significant contributions he was awarded the S. S. Bhatnagar Award in 1967 and the Krishnan Medal in 1965. He is also Foreign Associate of the US National Academy of Sciences, a rare honour for any scientist.

C. N. R. Rao

When eleven-year-old C.N.R. Rao and his classmates did very well in science, their teacher took them to meet the Nobel prize winner, C. V. Raman. For three hours Raman talked to them on physics and he also showed them his laboratory and equipment.

This visit had a lasting impression on Rao. He felt that science was fascinating. Besides, his parents encouraged him to take up science. His father used to talk to the boy about great scientists and their discoveries. So from his early childhood Rao was keen to become a scientist and do research.

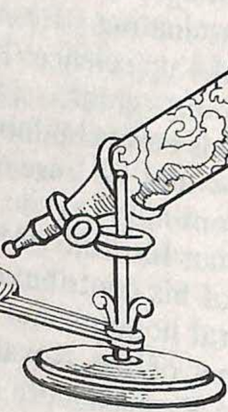
Even today he continues to do research in his laboratory at the Indian Institute of Science in Bangalore. In recognition of his contributions to chemistry, he has received several honours and awards. In 1982, he was elected Fellow of the Royal Society.

Chintamani Nagesa Ramachandra Rao was born on June 30, 1934. He had his basic education in Bangalore before joining Banaras Hindu University for his M.Sc.

He then went to Purdue University in the USA for his Ph.D. There he worked on various aspects of spectroscopy under Nobel Laureate H. C. Brown.

His research work is mostly confined to "solid state chemistry". Using various sophisticated tools of spectroscopy, Rao has tried to understand the inner structure of solids. These studies help in creating totally new types of solids with entirely new properties for use in industries. Besides, he has studied various phenomena occurring in solids at a microscopic level. For such studies he has built his own laboratory at the institute.

"Actually, doing science, rather than the results, is more exciting," says Rao.



In Lands Afar

R. C. Bose

Only a few days were left for his B.A. examination. Raj Chandra Bose was lost in his books. But his sister came with a problem. There was hardly any food left in the house. It was an urgent problem but nothing new. In the past three years he had faced one crisis after another. First, his mother had died in an epidemic and two years later his father had died.

At the age of 19 the entire burden of bringing up his brother and two sisters, all younger than him, had fallen on his shoulders. He had to take tuitions to earn for the family and he had won scholarships so that he could continue his studies. But finding money now was a problem. He had suspended tuitions to prepare for his examinations.

Then he remembered that there were still some medicines, including a bottle of quinine, in his father's medicine chest. It was soon after World War I and medicines were scarce and costly in India. A bottle of quinine fetched him a handsome amount. The crisis was overcome. Raj Chandra took his B.A. examination and passed it successfully.

Raj Chandra Bose was born on June 19, 1901, at Hosangabad in Madhya Pradesh and grew up at Rohtak, where his father was a doctor. Being the first child, his father had pinned high hopes on him. He always expected the boy to top his class. Once when he stood only second in geography in an eighth class test, his father forced him to learn his 200-page geography book by heart.

Pure mathematics had fascinated Bose from childhood. In 1925 no course in pure mathematics was available at Hindu College, in Delhi, where he had done his M.A. in applied mathematics. So, with the help of Seth Kedarnath Goenka, whose younger brother he had taught, he went to Calcutta. There he happened to meet Shyamadas Mukherjee, a mathematician, who not only gave him a room and allowed him the use of his library, but helped him in "learning the spirit of mathematics."

In 1927 he took his M.A. in pure mathematics, but he could not get a job. He was rejected everywhere for being "overqualified". He and his family had to live on the money he earned by teaching students. It was difficult, but he continued his research in geometry.

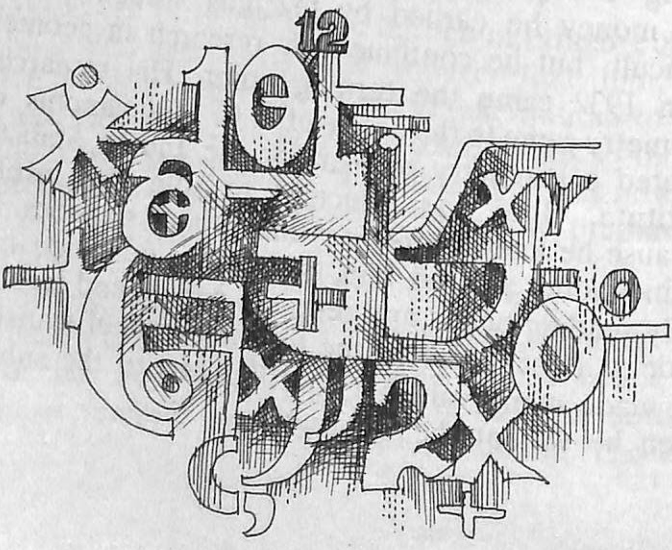
In 1932 came the turning point. His research in geometry came to the notice of P. C. Mahalanobis, who wanted a geometry scholar for the Indian Statistical Institute. Bose was reluctant to join the institute because he knew hardly anything about statistics. But Mahalanobis assured him that he would guide him.

By reading books and research papers and teaching students Bose mastered the fundamentals of statistics. He made many valuable contributions to the subject when he was at the institute.

In 1949 he migrated to the USA and joined the University of North Carolina as a Professor of Statistics. It was not money that tempted him to leave his homeland. It was only because he was offered a job which enabled him to devote all his time to mathematics. Later he became Professor of Mathematics and Statistics at Colorado University.

Two of Bose's discoveries won him much fame. Working with one of his students, he proved that a famous mathematical conjecture of the eighteenth century Swiss mathematician, Leonard Euler, was incorrect. Then, in collaboration with another student, he discovered new codes for telecommunication. Everyone knows the Morse Code. It is a code composed of dots and dashes used for sending messages over long distances via wireless telegraphy. However, because of what scientists call "noise", errors often creep into the messages. The Bose-Ray Chaudhuri codes could rectify the errors at the receiving end.

In 1976 America's highest honour to a scientist came to Bose. He was elected Fellow of the US Academy of Sciences.



S. Chandrasekhar

In 1946, a boyish-looking man was driving once every week from Yerkes Observatory in Wisconsin to the University of Chicago, a distance of 160 kilometers, to teach a class of two students, Tsung Dao Lee and Chen Ning Yang. Many wondered why he took so much trouble to teach these two students and why these students wanted this particular teacher. They had to wait some years for an explanation. In 1957 the two students were awarded the Nobel prize in physics.

The boyish-looking teacher was Subrahamanyan Chandrasekhar, one of the world's leading astrophysicists. Besides making significant contributions to the study of the stars, he has written books that are recognised as classics. He also won the Nobel prize in physics in 1983.

S. Chandrasekhar was born on October 10, 1910, in Lahore, now in Pakistan. He had his basic education in Madras. From childhood he was fond of reading. While most of his classmates never read books outside the syllabus, he visited the library regularly and read every new book in physics, even research journals.

Those were the 1920's when modern physics was taking birth. There was a flood of new, exciting discoveries. In particular books of such great scientists as Arnold Sommerfield and Arthur Compton drew Chandrasekhar to modern physics. And before he was 18 his research papers appeared in the *Indian Journal of Physics*.

By the time he did his B.A. (Hons) at the Presidency College in Madras, he had many papers to his credit. One of them even appeared in the proceedings of the Royal Society, a rare honour for one so young. In due course, he went to Cambridge as Fellow of Trinity College.

At the age of 27, Chandrasekhar's reputation as a promising astrophysicist had been established. When he reached the USA in 1937, the eminent astronomer and Director of Yerkes Observatory, Otto Struve, recognised his genius and offered him a job at the University of Chicago.

In the world of astrophysics Chandrasekhar is best known for "Chandrasekhar's limit". This imposes a restriction on the size of a highly dense variety of star known as the White Dwarf. If this type of star has mass in excess of the limit, it explodes like thousands of nuclear bombs ignited together to become a very bright star, called Supernova, until all the excess matter is shed into space. Although Chandrasekhar calculated his "limit" purely on mathematical equations, astronomers have found that all the White Dwarf stars in the sky have masses within his prescribed limit.

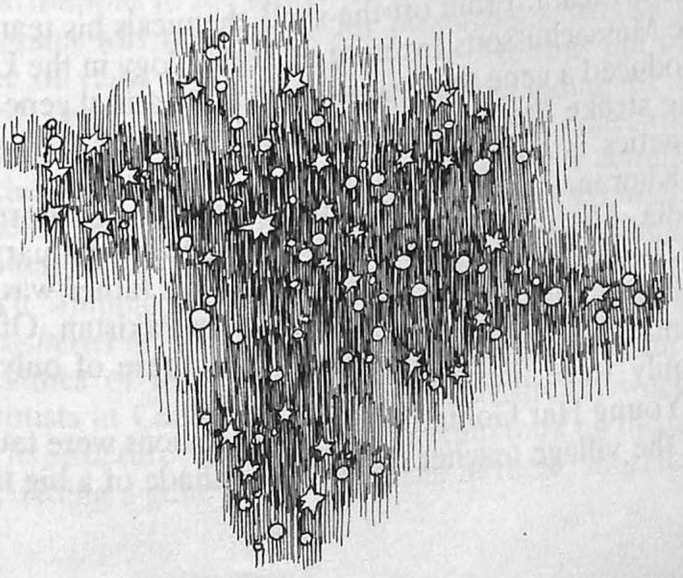
As early as 1935 he had come close to speculating on the formation of "black holes", superheavy heavenly objects, a spoonful of which weighs several thousands of tons. But contemporary astronomers were not prepared to accept that intriguing speculation.

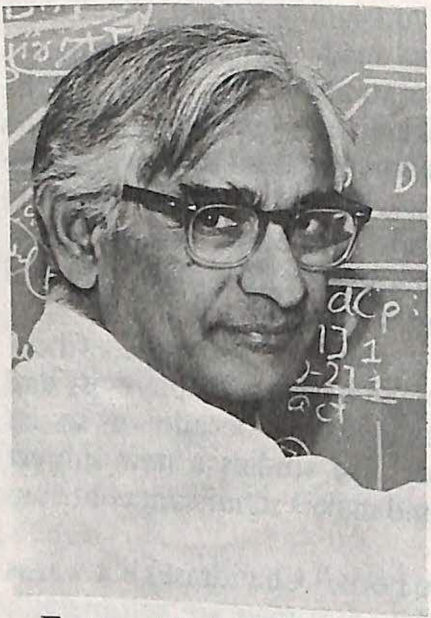
Chandrasekhar has also made significant contributions to understanding the atmosphere of stars and the way matter and motion are distributed among the stars in a galaxy. His work on rotating fluid masses and the blueness of the sky is also well known. Today, at the late age of 75 when most scientists retire, Chandrasekhar continues to study the effect of gravity and electromagnetic fields on rotating black holes.

Recipient of many medals and honours, Chandrasekhar is at once a physicist, an astrophysicist and an applied mathematician. Every decade or so he changes his field of study. He studies a new subject from scratch, masters it and makes significant contributions to it.

"Great men are seldom born," Chandrasekhar warns young boys and girls. "All great men are self-made".

Though he has lived in the USA since 1937, a visitor to his house might well find him wearing the south Indian *dhoti* and listening to Carnatic music.





H. G. Khorana

For mankind 1976 was historic. It was the year a fully workable gene was produced in the laboratory. The credit for this first step towards production of artificial life must be shared by many scientists, including those who laid the foundation of genetics. But a large share, perhaps the largest, should go to Har Gobind Khorana and his team. From off-the-shelf chemicals his team at the Massachussetts Institute of Technology in the USA produced a gene that was as good as a natural gene. At one stroke the team showed that the entire edifice of genetics is correct.

Khorana, now in the United States, was born in India. His date of birth is assumed to be January 9, 1922—the exact date is not known. His father was the village tax-collector at Raipur, now in Pakistan. Of the hundred people in that tiny village, those of only his family were literate.

Young Har Gobind's first school lessons were taught by the village teacher sitting in the shade of a big tree.

He did his B.Sc. and M.Sc. in chemistry at the University of Punjab in Lahore and, in 1945 went to the University of Liverpool in Britain on a Government of India scholarship. On his return with a Ph.D. in organic chemistry, he found he could not get a suitable job. When his application for a teaching post at the University of Delhi was rejected, he decided to go abroad.

Khorana first made his name in 1959 when he produced a chemical called "coenzyme A", which is essential for certain processes in the human body. He was then at the University of British Columbia in Canada. From there he moved to the Institute of Enzyme Research of the University of Wisconsin in the USA. In 1970 he joined the Massachussetts Institute of Technology as the Alfred Sloan Professor of Biology and Chemistry. "You stay intellectually alive longer," he once said, "if you change your environment ever so often."

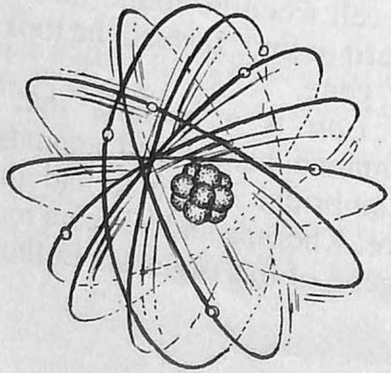
At the age of 46 Khorana shared the 1968 Nobel prize for medicine with Marshall W. Nirenberg and Robert W. Holley. All three had independently made contributions to the understanding of the genetic code. Khorana was responsible for producing a part of the gene of yeast cell in his laboratory. He thus not only filled some vital gaps in the understanding of the genetic code, but showed how the genetic code works in the cell. Later, he abandoned building a complete gene of yeast cell when he found that full knowledge about it was hard to find. Instead, he took up building a much simpler gene.

Escherichia Coli is a bacteria that lives in the intestines of human beings and animals. A team of scientists at Cambridge in Britain had already worked out its structure. Khorana and his team took up the task of building a gene of this organism in their laboratory.

Piece by piece, they built up the 207 gene of *Escherichia Coli.* Signals of "stop" and "start" were also added to the gene. The climax came in August, 1976, when the man-made gene was "inserted" into *Escherichia Coli.* It began to work like its natural gene. This achievement was hailed the world over as a major triumph of modern biology.

On paper the production of a gene may appear easy, but it is not so in practice. To produce one gene of *Escherichia Coli* bacterium it took Khorana and his 24 team members nine years of consistent labour. Production of a human gene is still a distant possibility, if not a dream. One human gene is very much bigger than a *Escherichia Coli* gene and is even more complex. "You too can win the Nobel prize", Khorana wrote to his students when he went to Stockholm to receive the prize. "Do not let your so-called shortcomings overshadow your progress."

Khorana is at present studying how a gene functions in a cell, why it works when wanted and what makes it stop. Now that a gene can be made in the laboratory, he wants to make the necessary changes in it and observe how they affect the cell machinery and thus the organism. His studies may tell us what causes genetic defects and how to correct them. It may also tell us how and why cancer is caused.



K. K. Pandey

It was the agriculture science period for the ninth class at the Kshattriya High School at Jaunpur in Uttar Pradesh. The teacher, Thakur Bali Raj Singh, was examining the homework done by his students. The previous day he had asked them to write on "seeds dispersal".

What one boy had written amazed him. "Kamla Kant," he called. A shy boy stood up. "Are these your thoughts?" the teacher asked. When the boy nodded, the teacher asked, "Have you read Charles Darwin's theory of evolution?" The boy showed complete ignorance. "Come here, please," the teacher said. He patted the boy and, facing the students, said, "Kamla Kant Pandey has, on his own, written the theory which the great naturalist Darwin had put forward in the last century. I am sure Kamla Kant will one day be a great scientist."

He could not have been more correct. Kamla Kant Pandey is today one of the most notable plant geneticists in the world. He is now head of the Genetics

Unit, Department of Scientific and Industrial Research, New Zealand.

In 1975 he made the discovery of a revolutionary technique in plant breeding. By his technique selected genes of a flowering plant can be transferred to another plant. He made use of strong nuclear radiations to break the genetic material of a plant and separate the desirable genes from the undesirable. The discovery was hailed in New Zealand as "the most important discovery by a New Zealander since Lord Rutherford split the atom."

Every gene controls some characteristic of a plant or an animal, for instance, height or colour. By the conventional breeding techniques, when a cross is made between two plants, both the desirable and undesirable characteristics of the genes of the parents are transferred to the offspring. By Pandey's technique only those genes of the parent plants that would give the offspring the desirable characteristics could be eliminated or suppressed. Plant breeders can thus improve the variety of a plant without wasting time and effort.

A gene known as the "S-gene" also governs whether a plant can self-pollinate or cross-pollinate. Pandey was among the first to point out that the "S-gene" also controlled the ability of a plant to cross with another species of plant. He studied the "S-gene" in detail and found that it was actually a nest of gene, a "supergene". His research showed that this supergene was very important in the evolution of flowering plants. It produces chemicals that influence the breeding behaviour of plants.

Pandey also used the irradiation technique to change the mechanism of the "S-gene" and thus brought changes in the breeding behaviour of a plant. Thanks to his researches, cross-pollinating plants can now be "made" self-pollinating. Bees are no longer essential for cross-pollination.

Pandey was born on December 11, 1926, at Varanasi. He was the first Indian agriculture graduate to win the London Exhibition Scholarship. He joined the John Innes Institute in London to do research on plant genetics. After taking his Ph.D. in 1954, he went to New Zealand and settled there. In 1966 he was elected Fellow of the Linnean Society of London, a rare honour for any botanist. In 1970 he got the D.Sc. of London University. Besides his valuable discoveries and techniques, he has also put forward a theory of vertebrate evolution in animals.

Govindjee

To re-live the era of discoveries in photosynthesis, a mock seminar was conducted at the University of Allahabad in 1952. Six young boys dressed in various European costumes, dirty gowns, old hats and baggy trousers, with powdered faces and thick moustaches, acted like the scientists who had made significant contributions to the understanding of photosynthesis.

The role of Jan Ingenhouz, the eighteenth century physician who experimentally showed that photosynthesis takes place only in the presence of light, was played by Govindjee, the organiser of the seminar. Like Ingenhouz, he argued that photosynthesis is vital to life on earth, that it gives oxygen to breathe and food to eat.

When the seminar concluded, there was much laughter and applause. The acting of the boys was praised. But no one present there must have thought that one day young Govindjee himself would make valuable contributions to the understanding of photosynthesis.

Govindjee is now Professor of Biophysics and Botany at the University of Illinois, USA. He was once introduced to the audience at a seminar held at Los Alamos Laboratory, New Mexico, thus: "We depend upon photosynthesis and photosynthesis depends upon Govindjee."

Photosynthesis is a process that takes place in green plants in sunlight. The green plants convert carbon dioxide from the air and water from the soil into oxygen and carbohydrates (molecules composed of carbon and hydrogen atoms). The plant releases oxygen and uses carbohydrates for its own growth.

The sites in plants where photosynthesis takes place are called "chloroplasts". They contain a green pigment called chlorophyll. The pigment converts the incoming light energy from the sun into complex chemical compounds. The compounds further react with carbon dioxide and water in a complicated manner to produce oxygen and carbohydrates. The exact mechanism of this process is not yet known.

In collaboration with his students, Govindjee has been exploring the mechanism that enables plants to evolve oxygen and has been successful to a large extent. If man is able to understand photosynthesis fully, food production could be easily increased. There will no longer be hunger on earth.

Govindjee was born on October 24, 1933 in Allahabad, U.P. His father, Visheshwar Prasad, who was an educationist, did not believe in caste and creed and so dropped their family name of Asthana. Visheshwar Prasad died when Govindjee was hardly eleven. His mother was in poor health and so his elder brother, Krishnaji, brought him up. Krishnaji remembers that Govindjee was an inquisitive child, wanting to know the why and how of everything he saw. "Govindjee", he says, "was fond of discussions to the extent that he disliked those who avoided discussion."

Govindjee was interested in biology and physics from his school days. Fortunately, he had good teachers, one of whom introduced him to the wonders of nature. He used to watch the plants that grew in the little garden of his school for hours. Another teacher sharpened his interest in biology by explaining the subject in an exciting manner. Govindjee remembers he was good at learning from books but was always unsure of himself at practicals. Maybe this was the reason why he took up botany. He found cutting of plant sections easier than disection of animals.

After taking his B.Sc. and M.Sc. from the University of Allahabad, standing first in the University in the latter, Govindjee left for the USA. in 1956.

A. M. Chakrabarty

Oil is transported in huge tankers over the seas. During the voyage, oil from the tankers leaks into the sea. Such pollution affects marine plants and animals. Some are crippled and some die. No solution to this problem appeared possible till Ananda M. Chakrabarty created a remarkable "bug".

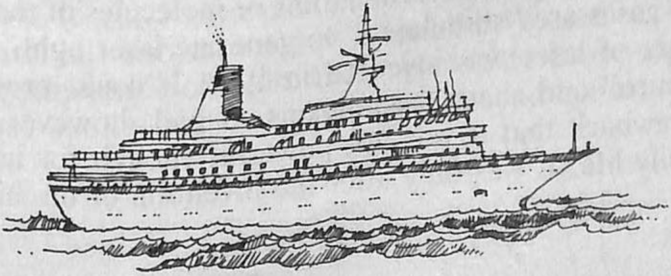
Psuedomonas is a class of bacteria which can eat different compounds of hydrocarbons, molecules made up of carbon and hydrogen. Crude oil is a complex mixture of such compounds, called "Fractions". The *psuedomonas* bacteria could, therefore, be used to eat oil spilled on the sea, but each strain of the bacteria eats only a particular hydrocarbon compound and does not function, or even survive, if another hydrocarbon compound is present. The need was for a strain of bacteria which could eat many hydrocarbon compounds. Chakrabarty invented such a superstrain.

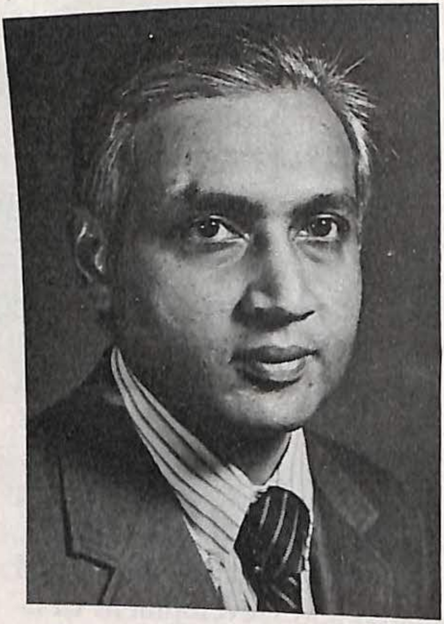
Chakrabarty was born on April 4, 1938, in Sainthia, 190 km. from Calcutta. His father was a rice and coal merchant, who, though he was not rich, wanted to give his children a good education. Ananda was sent to a distant school, the Ramakrishna Mission Vidyamandir at Belurmath. Here the monks taught him to become a rational thinker and spend a disciplined life.

After doing his B.Sc. at St. Xavier's College in Calcutta, he did his M.Sc. and Ph.D. at the University of Calcutta. He has great regard for his research guide, Professor S. C. Roy, who told him "how to go ahead experimenting with uncommon ideas not popular or even realistic at the time." It was Roy who advised him to shift his interest from biochemistry to molecular genetics.

In 1965 Chakrabarty left for the USA. He first took up research in molecular genetics under Professor I.C. Gunasalus at the University of Illinois and later joined the General Electric Research and Development Centre. During research there he found that under the optimum conditions of time, temperature and nutrients, the hydrocarbon-eating "qualities" of four different strains of bacteria could be transferred into one. He also showed that his superstrain of bacteria reproduces itself.

For the first time an artificial "bug" was thus created. Chakrabarty's now patented "Superbug" digests hydrocarbons at a far faster rate than naturally occurring bacteria. It converts the hydrocarbons into a harmless protein-rich food which could be easily eaten by marine animals.





C. K. N. Patel

Laser is the acronym for "light amplification by stimulated emission of radiation." Though it is like ordinary light, laser is far different. In the filament of a bulb, the atoms gain electric energy and release it in the form of light. The atoms in this case behave like a crowd whose footsteps are not in order. In the case of laser, the atoms are "stimulated" or forced to behave like an army battalion. Their footsteps are in perfect order.

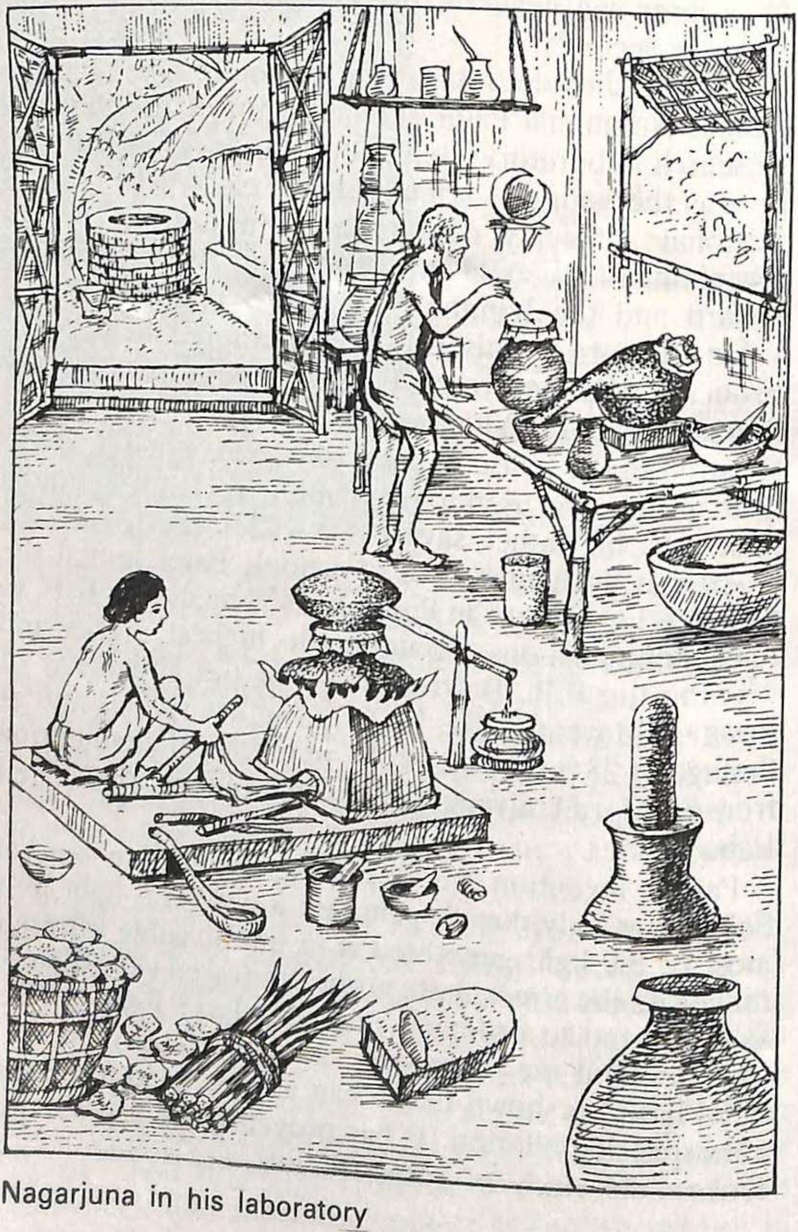
Laser is, therefore, light of a highly ordered type. It is packed with tremendous energy, unlike ordinary light. Laser is called solid, liquid or gas laser depending on whether its source for atoms is solid, liquid or gas. In the case of gas laser, the atoms or molecules of the gas or gases are "stimulated" to generate laser light. This type of laser was invented in 1960. It could produce "pure" and sharp laser beams. It had, however, the drawback that it was not powerful enough for use in daily life. It was only after the invention of the highly powerful carbon dioxide laser that laser found applications in several branches of science and technology. Now laser can generate enough power to cut a steel plate in seconds.

Carbon dioxide laser was invented by Chandra Kumar Naranbhai Patel, now Director of the Physical Research Laboratory, Bell Laboratories, USA. In 1974 he was the youngest scientist to be elected to the US National Academy of Sciences. Besides, he is the recepient of the Ballantine Medal, the Zworykin Award and the Lamme Medal.

He was born on July 2, 1938, at Baramati, near Pune. From his childhood young Patel was eager to know how things worked. Whenever any gadget was to be repaired in the house he used to pounce upon it. After dismantling it he used to reassemble it. He always did a neat job, his father says.

After a brilliant record in school, Patel joined the Engineering College in Pune. In 1958 he did his B.E. in telecommunications, securing the highest marks and winning the P.R. Bastikar Prize of the University of Poona. He went to the USA for higher studies and at the age of 23 he took a Ph.D. in electrical engineering from Stanford University. The same year he joined Bell Laboratories.

Patel's invention has found applications in several fields. Not only does it generate a powerful light, but most of the light generated is in the invisible infrared range. As the atmosphere absorbs infrared very slightly as compared to ordinary light, this laser light can be used to send messages over the earth and in space. Patel has also shown that it can also be used to detect atmospheric pollution. It has proved to be a powerful tool in the study of gases, liquids and solids.



Nagarjuna in his laboratory

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